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OF THE

UNITED STATES GEOLOGICAL SURVEY,

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TWENTY-SECOND ANNUAL REPORT

OF THE

UNITED STATES GEOLOGICAL SURVEY

PART II—ORE DEPOSITS

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THE OLD TUNGSTEN MINE AT TRUMBULL, CONN.

BY

WILLIAM HERBERT HOBBS

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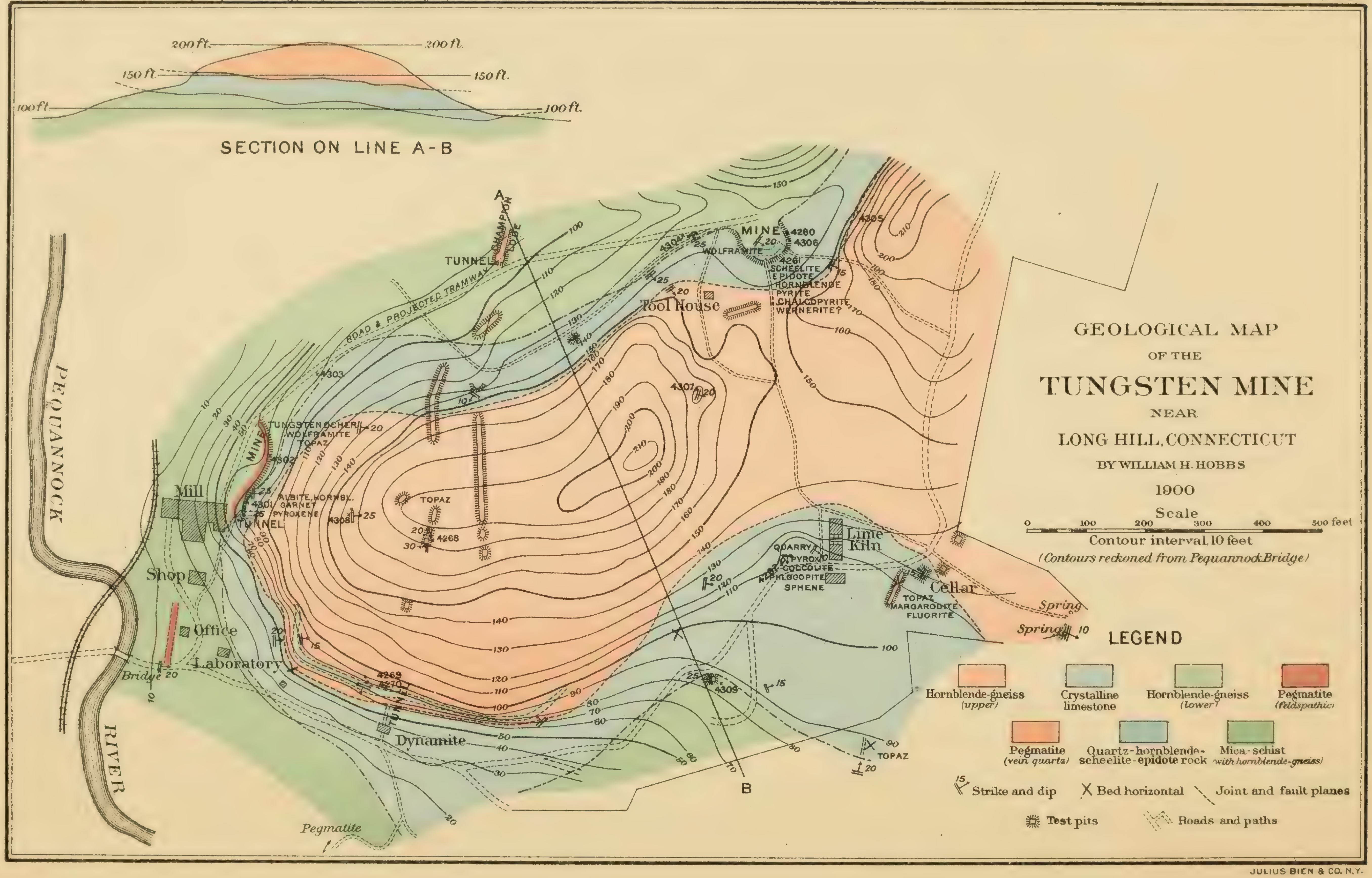


GEOLOGICAL MAP
OF THE
TUNGSTEN MINE
NEAR
LONG HILL, CONNECTICUT
BY WILLIAM H. HOBBS
1900

Scale
0 100 200 300 400 500 feet
Contour interval, 10 feet
(Contours reckoned from Pequannock Bridge)

JULIUS BIEN & CO. N.Y.

THE OLD TUNGSTEN MINE AT TRUMBULL, CONN.

By William Herbert Hobbs.

INTRODUCTION.

The locality of Trumbull, Conn., has long possessed an exceptional interest for mineralogists, owing to the occurrence of the rare tungsten minerals with their characteristic associates. It is of particular interest, however, because of the occurrence of wolframite with the crystal form of scheelite, indicating that the wolframite has been produced by alteration of scheelite through replacement of its calcium by iron and manganese. The original openings bore the name of Lane's mine of Trumbull. On account of the occurrence of native bismuth and galena on the property of a Mr. Lane in the adjoining township of Monroe and the opening of pits there, much confusion has arisen, and there are many references to an occurrence of wolframite in Monroe, which, with little doubt, are meant for the Trumbull locality.[1] Shepard, however, emphasizes the occurrence at the Monroe locality of scheelite (pyramidal tungstic baryte), both massive and crystallized, the former in masses 2 inches in diameter.[2]

The Trumbull locality is near the summit of Long or Skag-ne-wamp Hill, a rounded knoll which rises about 200 feet from the banks of Pequannock River, at a point near the tracks of the Bridgeport branch of the New York, New Haven and Hartford Railroad, and about one-third of a mile north of the station of Long Hill.

The openings made by Charles Lane were later worked in a primitive fashion by Thomas R. Hubbard, though for "copper, lead, and silver," the wolframite minerals being sought by mineralogists only. Still later the limestone on the property was worked for lime burning and the pegmatite veins for the materials of porcelain, but no important exploitation of the wolframite minerals was undertaken until 1898, when extensive operations were begun by the Rare Minerals Mining Company. The control of the property passed eventually to the American Tungsten Mining and Milling Company, which until very recently operated it.

---

[1] The mine of Mr. Lane at Monroe is opened in a wide vein of quartz, which has a northerly trend. No wall rock is here exposed. The vein is rich in marcasite, and the mineral collection of E. S. Olmstead, of Long Hill, contains also sphalerite, galena, arsenopyrite, and native bismuth, all from this locality. The occurrence of these minerals at Monroe is apparently in no way connected with that of the tungsten minerals in the neighboring town of Trumbull, the associated minerals being quite different in the two localities. The confusion which has arisen has been due largely to the propinquity of the two localities and to the fact that both mines were owned by men bearing the same surname.

[2] Rept. Geol. Survey Connecticut, New Haven, 1837, pp. 123, 172.

EARLY STUDY OF THE AREA.

Percival early called attention to the occurrence of the minerals of the Trumbull mine in limestone associated with hornblende-gneiss.[1]

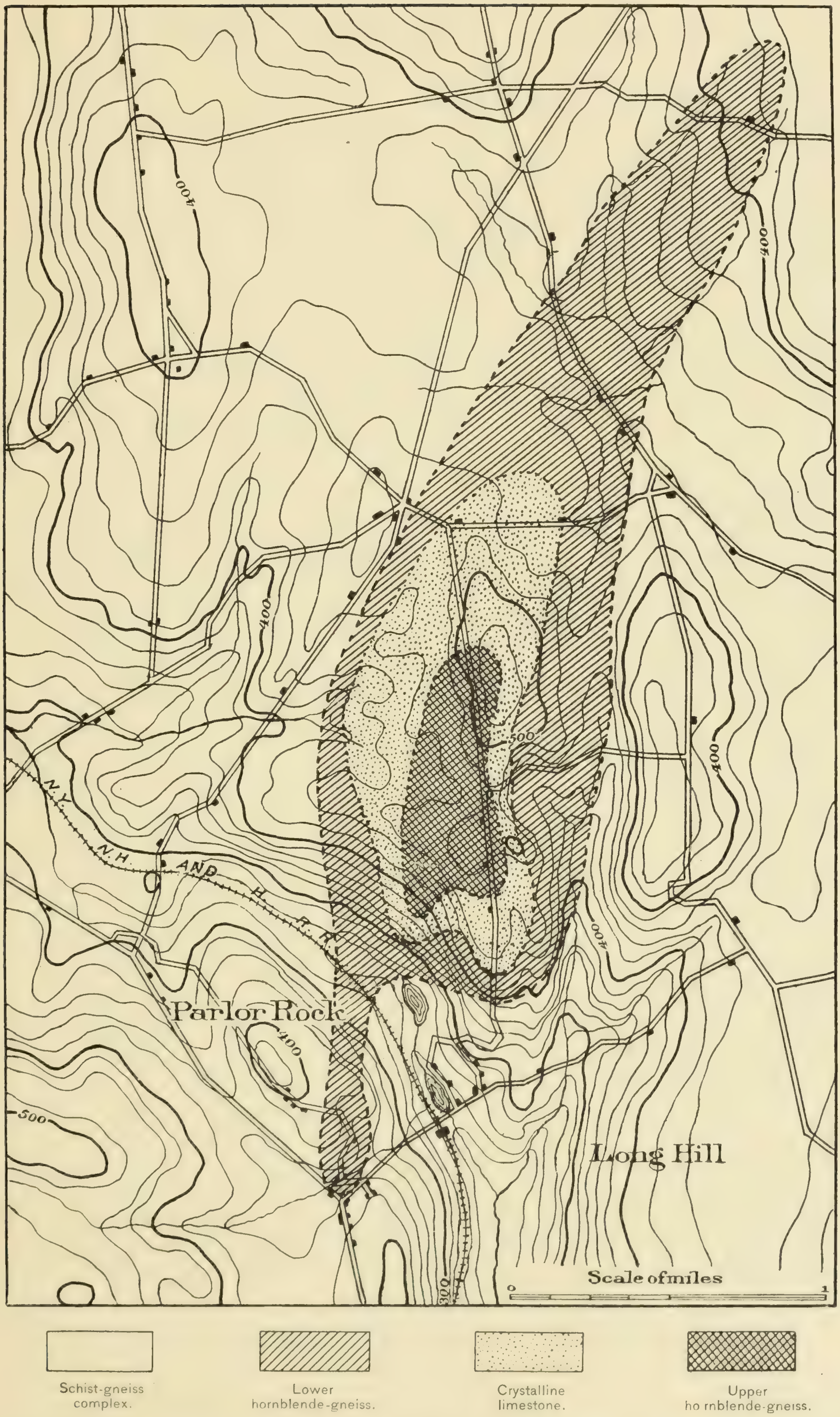
Prof. Adolf Gurlt, of the University of Bonn, visited the locality in 1887, and reported upon it in a paper read at the Chicago meeting of the American Institute of Mining Engineers in 1893.[2] His observations, which were very carefully made, give an excellent idea of the locality before any extensive openings had been begun. Of the geology he says:

> Hubbard's mine is in a district composed chiefly of a younger metamorphic amphibole gneiss, of a dark, blackish color, containing quartz, feldspar, mica, and amphibole, alternating with beds of mica-gneiss, in which mica predominates. The gneiss incloses a bed of crystalline limestone 35 to 45 feet thick, exposed over an area of about 25 acres, and only covered by gneiss in South Hill, near the southern boundary of the property, where the copper, lead, and silver mining had been carried on. The limestone is highly crystalline—in fact, a marble—and is intersected by several true-fissure veins, in the neighborhood of which it contains foreign minerals, such as mica, pyroxene, analcite, and amphibole. The lodes or veins are in no sense confined to the limestone, but traverse the underlying as well as the overlying gneiss.
>
> The wolfram ore, consisting of wolframite, scheelite, and wolfram-ocher, occurs upon a so-called contact deposit 3 to 5 feet thick, which is embedded between the crystalline limestone and the lower gneiss, and is conformable with their general dip and strike. It is evident that this contact deposit is intimately connected with the above-described lodes which traverse it, and that to them, as feeders, it owes a great portion of its minerals, which may have been deposited from solutions or thermal waters that rose along the fissure lodes and found lateral vents along the contact of the gneiss and limestone. The close genetic connection of the lodes and the ore bed seems to be confirmed by the fact that the topaz vein occasionally yields wolfram minerals. When I visited the mine, I found on the western outcrop of the ore bed, about midway between the topaz and quartz lodes, a few shallow pits and a short adit in the gneiss. The pits had been sunk vertically through the ore bed into the gneiss and then had been abandoned instead of following the bed, which dips east 20° to 25°. Nevertheless a not inconsiderable quantity of wolfram ore, chiefly scheelite and wolframite, had been taken out. I put a couple of laborers at work in these small excavations and also sunk costeaning pits at other points along the outcrop, always following the slope of the bed, and, though I had only a few days at my disposal, some rather significant results were obtained.
>
> In its principal mass the ore bed consists of vitreous, translucent quartz of an entirely different character from that of the Champion and topaz veins. It usually forms a compact mass, containing cavities or druses studded with quartz crystals that are frequently covered by a thin film of yellow wolfram ocher. The quartz penetrates through crevices and fissures into the limestone and the amphibole gneiss,

---

[1] Rept. Geol. Connecticut, New Haven, 1842, p. 43.

[2] On a remarkable deposit of wolfram-ore in the United States: Trans. Am. Inst. Min. Eng., Vol. XXII, 1894, pp. 236–242.



GEOLOGICAL MAP OF THE VICINITY OF THE TRUMBULL MINE.

both of which near the contact must therefore be taken as part of the ore bed. The quartz also contains iron pyrites, epidote, calcite, mica, and the wolfram minerals, scheelite and wolframite. The latter occur embedded not only in the quartz, but in the adjoining metamorphosed beds of the country rock as well-shaped crystals or solid lumps and strings. The crystals are numerous and often of considerable size. It is remarkable that the wolframite crystals never show the peculiar crystallization of this mineral, but always that of scheelite. They are really pseudomorphs, and indicate that the original wolfram mineral was scheelite or tungstate of lime, which was subsequently altered into tungstate of iron and manganese. The crystals are sometimes only partially converted, showing both minerals in the same individual. Both the crystals and lumps are usually loosely embedded in the matrix, and easily detached.

As the ore bed is traceable all along the outcrop between the limestone and gneiss, it is probably continuous in the whole basin of the gneiss, which is filled by the limestone over a surface area of about 25 acres. It is to be supposed that the wolfram minerals are not uniformly distributed through the whole bed, but that rich and poor spots will be found.

FIELD WORK.

The extensive operations of the present owners and of the mining companies recently in control of the property have afforded new opportunities to study the geology of the area, and accordingly, in the season of 1900, the writer prepared a topographic and areal geologic map of the exploited property, and examined with some care the material of the several veins. The hill known as Long Hill is made up of two beds of hornblende-gneiss, separated by a bed of crystalline limestone 20 to 30 feet in thickness (see Pl. I). The lower of the two beds of hornblende-gneiss forms the pedestal of the hill, and rests upon a complex of silvery micaceous schists and granitic gneiss, which characterize much of the surrounding territory. The upper bed of hornblende-gneiss, which has no marked petrographic characteristics to separate it from the lower, forms the cap of the hill. The intervening bed of limestone can be followed entirely around the hill on its western, southern, and eastern flanks, and to the northward in two belts for a half mile or more beyond the mining property. Here its exposures, still separated by outcroppings of hornblende-gneiss, indicate that the limestone forms the opposite limbs of a shallow basin. The dying out of the limestone outcrops near this point probably indicates that the southward-pitching axis in the northern part of the basin brings the underlying basement of schist and gneiss to the surface (see Pl. II).

PETROGRAPHY.

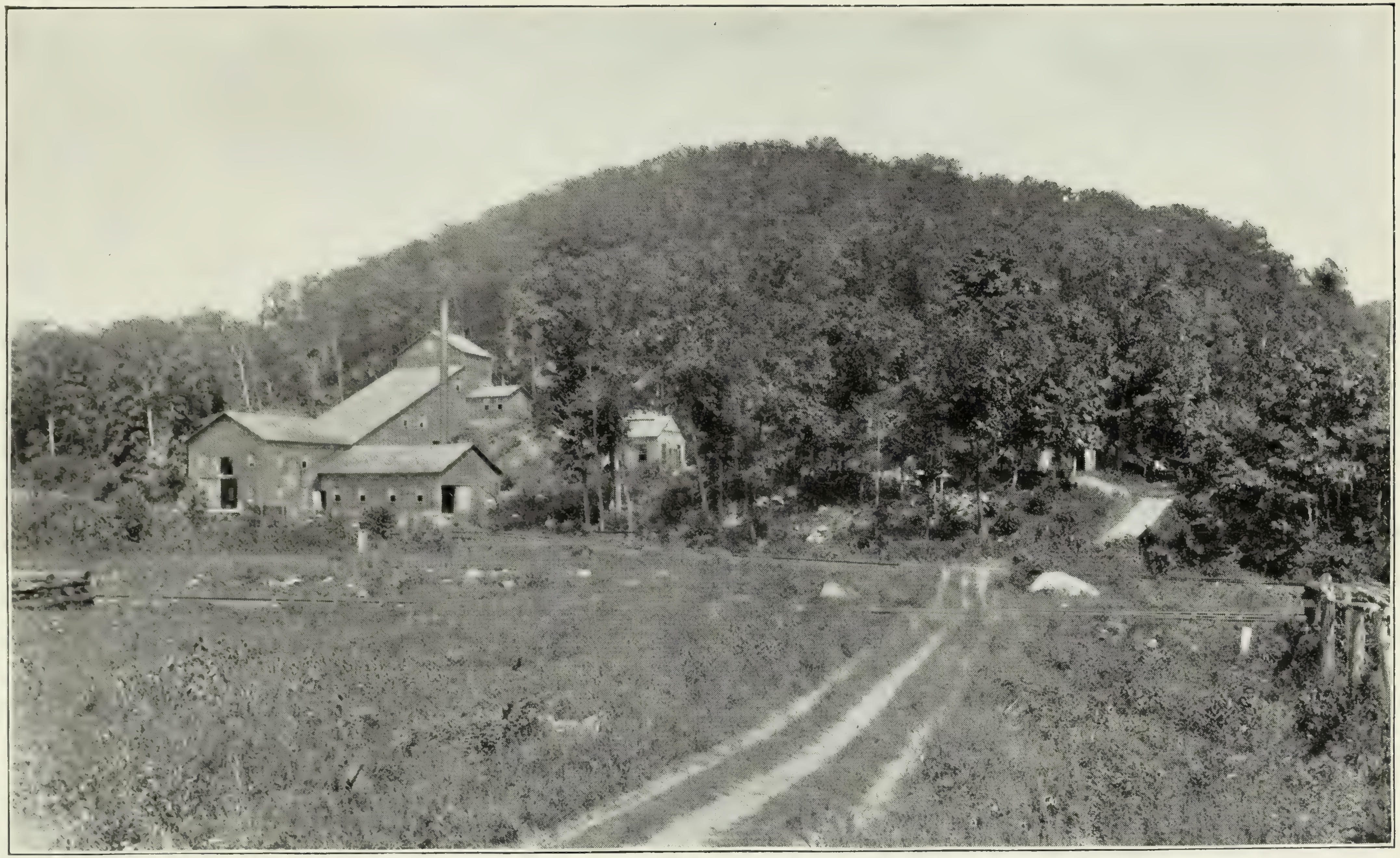
The field observation that the upper and lower beds of the hornblende-gneiss, which are separated by the thin band of limestone, are in all important respects identical is confirmed by an examination of the microscopic sections. The schists and gneisses that form the immediate basement upon which rest the hornblende-gneiss and limestone afford no interesting contacts with the hornblende-gneiss, and it will here suffice to state that they are of extremely variable character, though generally a very silvery mica-schist in which are scattered dark-red garnets, and with which are frequently associated the other metamorphic minerals common to the schists of the region.

HORNBLENDE-GNEISS.

In specimens obtained from a distance of 20 feet or more from the contacts, both above and below the limestone, this rock is a moderately coarse-grained diorite which shows but slight evidence of gneissic structure. As shown by its extinction angles, the feldspar is an oligoclase or andesine, remarkably fresh, twinned according to the albite law and more rarely according to the pericline and Carlsbad laws. Zonal structure is not a marked feature. The principal nonfeldspathic constituent is a fresh green hornblende with a slight tinge of brown when the ray vibrates parallel to **c**. Biotite also, in large blades, while often almost absent, in some specimens is present in quantity equal to one-fourth or one-third the hornblende. In these specimens the contacts between the hornblende grains and the feldspar are sharp, with no trace of fraying out in the former. Sphene is fairly abundant, sometimes with a core or eye of ilmenite. The sphene thus associated with ilmenite is generally nearly colorless and without definite form, whereas the other grains often show the lozenge-shaped basal sections and have a browner hue. Quartz, if present, is in very sparing quantity. Pyrite and apatite are unimportant accessories.

In the more massive specimens the crystals of hornblende are joined in a network about the feldspars. Petrographically these specimens are hornblende-diorite, and their igneous origin can scarcely be doubted.

As the contact with the limestone is approached the diorite changes in character. A gneissic structure becomes more pronounced in the hand specimen, and the rock becomes paler, owing to the diminution of the amount of hornblende. The apparent size of the grains is increased also. Examined in thin sections, these changes are seen to be due chiefly to the introduction of new minerals, most abundant of which are zoisite-epidote, calcite, and quartz. Sphene also, of the brown variety, seems to be augmented in quantity. The hornblende, instead of being in large single individuals, is frayed at the edges, in radial bundles of fibrous crystals, or, what seems more commonly to be the case, in a closely matted web of long columnar to acicular crystals, like those into which the pyroxene of certain diorites and gabbros breaks up when much affected by dynamic forces. Very near the contact the rock is often fully three-fourths zoisite-epidote. These specimens are frequently much stained by oxide of iron.



VIEW OF TUNGSTEN MINES, LONG HILL, CONNECTICUT.

In the foreground is seen the mill of the American Tungsten Mining and Milling Company.

LIMESTONE.

The thin limestone bed which separates the two beds of hornblende rock is a coarsely crystalline marble, and near the center of the bed it is nearly 92 per cent carbonate of lime and almost free from magnesia, the residue being largely silica. Petrographically it has no special interest, except when modified, as it is near its contacts. At the quarry near the limekiln the rock contains pink, blue, and black calcites, and is very coarsely crystalline. It abounds in blades of a brown mica, and contains also crystals of pyrite, pyroxene, etc. An analysis of the purer marble, made by S. C. Eaton, of the Brooklyn Polytechnic Institute, as reported by the mining company, is as follows:

Analysis of marble, by S. C. Eaton.

Constituent.	Per cent.
SiO_2	3.4
Al_2O_3	1.5
Fe_2O_3	0.6
$CaCo_3$	91.8
MgO	0.6
Ignition	2.1
	100.0

GEOLOGICAL STRUCTURE.

Structurally the beds of diorite and hornblende-gneiss with their intercalated layer of crystalline limestone form a nearly horizontal waving monocline or gentle syncline, which the topography slightly exaggerates. No dips higher than 25° were observed in the limestone. The contacts show essentially conformable bedding, the gneissic marginal planes of the gneiss being practically parallel to the well-marked bedding planes in the limestone (see Pl. IV, *B*). On the southeastern flank of the hill is found a second layer of limestone, 4 to 5 feet in thickness, and some distance within the upper layer of hornblende-gneiss. This layer of limestone in the section above the laboratory building includes a layer of hornblende rock a foot or more in thickness.

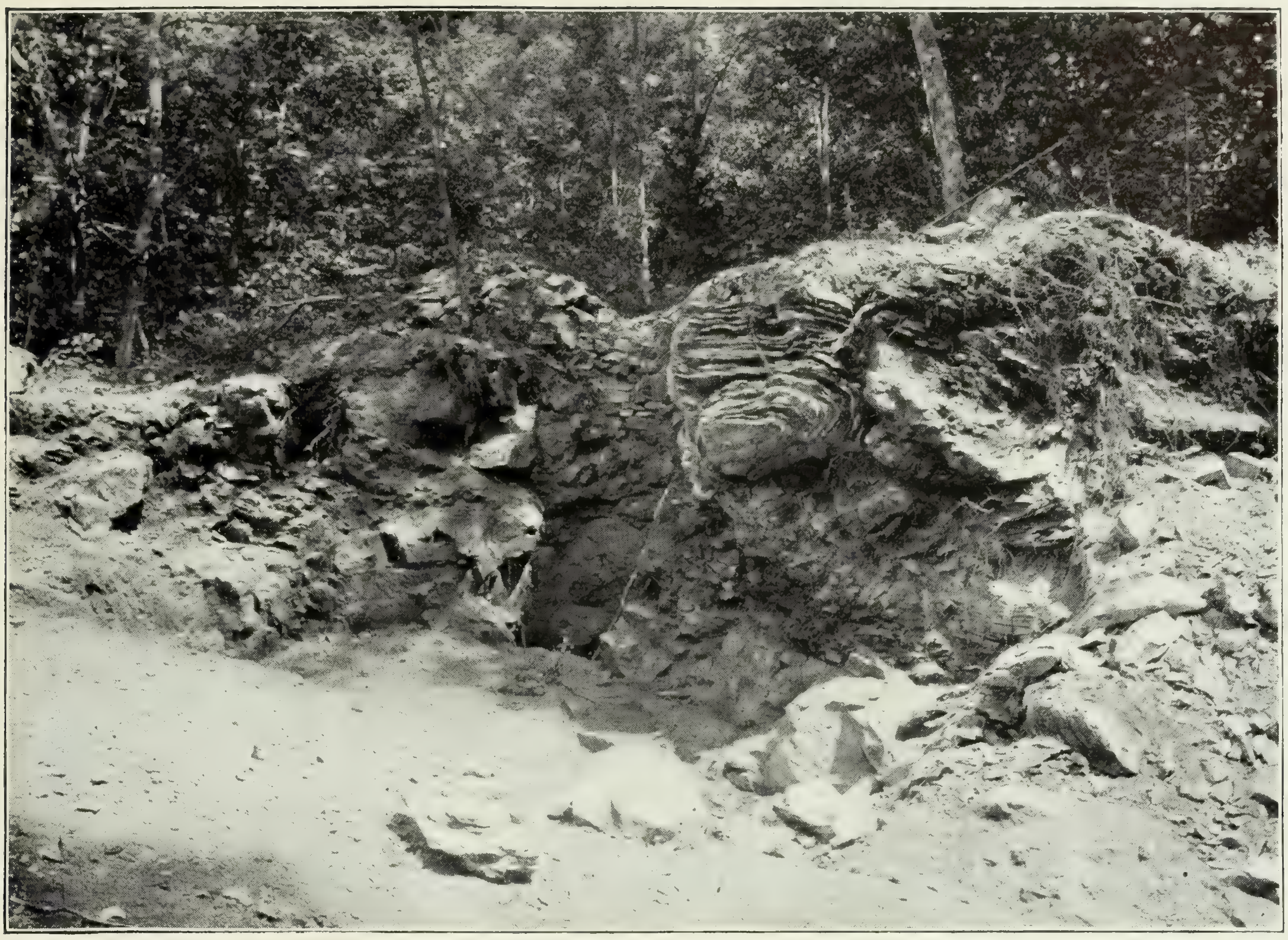
At most localities where the limestone has been opened the presence of nearly vertical and parallel series of joint or fault planes is noticeable (see Pl. V, *B*). The displacements along these planes of jointing are seldom more than a foot or two, with the exceptions which will be noted below. While the strike of these planes could not be determined with accuracy, the rough measurements N. ± 55° E., N. ± 80° E., N. ± 10° E., N. ± 35° W., N. ± 45° E. will indicate the complexity of the system. The fault which is represented in Pl. V, *A*, cuts the limestone in a vertical plane, and shows well the effect of drag along the fault. This locality is some distance east of the Sage place, and a short distance east of the mining property. The crumpling of the limestone along a fault is well brought out in Pl. V, *B*, which is a view of the east wall of the main mine opening at the top of the hill, as it appeared in July, 1900. It is significant that in western Connecticut faults should be so generally recognizable wherever layers of rocks of markedly different characteristics appear at the surface, and this gives emphasis to the fact that in a great majority of instances in areas of crystalline rocks faults will elude observation.

MINERALS OF THE CONTACT ZONES.

Especial interest attaches to the zones of contact of the limestone and hornblende-gneiss because of the marked changes of the rocks near these contacts, the exceptional nature of the included minerals and their alteration products, and because here is found the tungsten ore. Essentially the same minerals are found at the two limestone contacts, though the tungsten minerals, scheelite and wolframite, are generally more abundant at the lower contact. Laterally this contact bed shows marked differences not only in the nature of the included minerals, but also in their abundance. The large number of test shafts, slopes, and drifts which have been made at different times give considerable value to generalizations, but they chiefly emphasize the fact that as regards the distribution of the tungsten minerals no law can be laid down, save the one that the ore is concentrated just below the lower contact, with the widest variations as regards its lateral distribution.

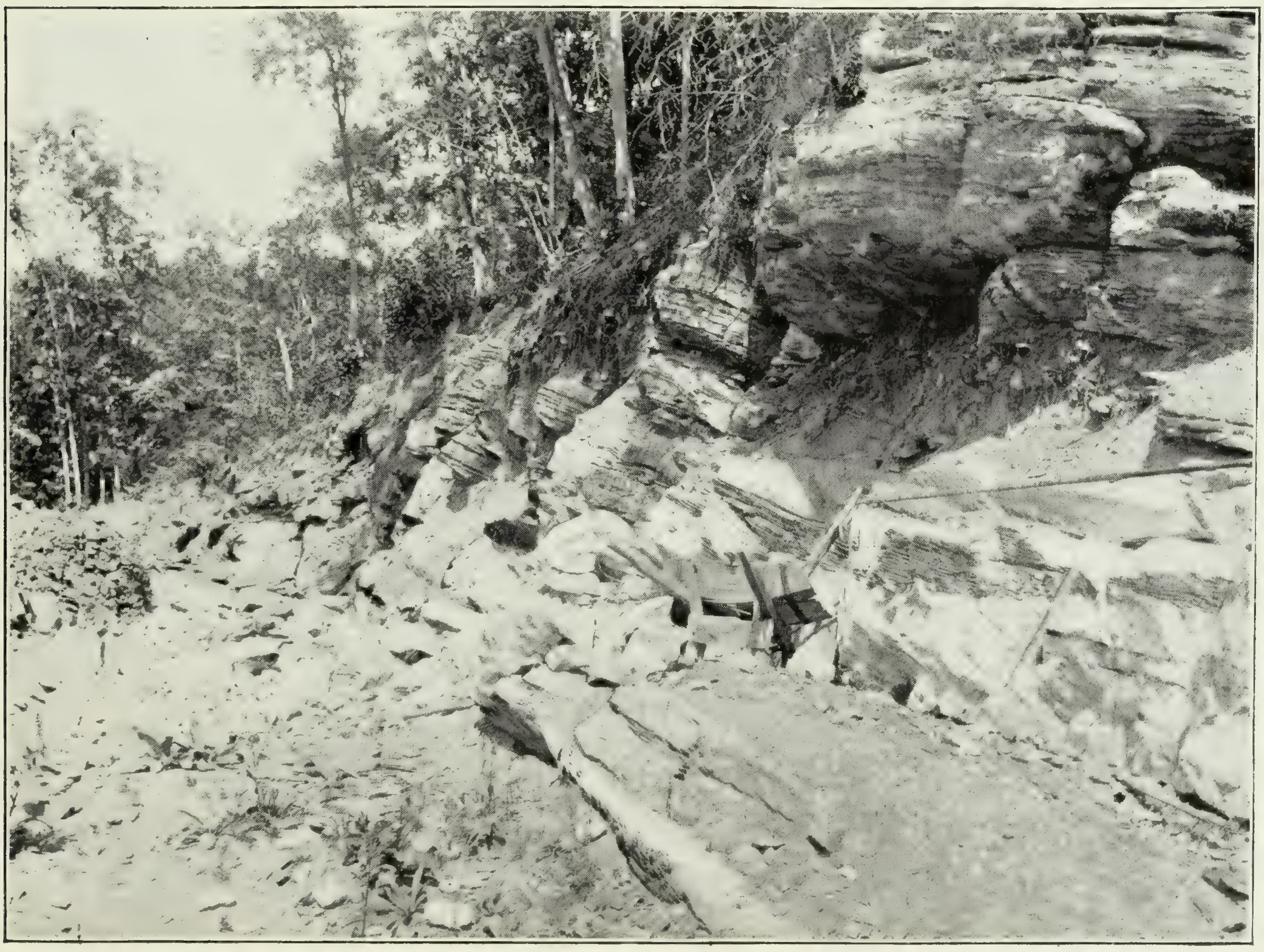
In the main opening at the summit of the hill the fresh contact rock is a massive quartz-zoisite-epidote-hornblende rock, extremely dense and difficult to drill. In this rock scheelite is irregularly disseminated and often concentrated in crystalline masses which are sometimes as large as the fist. Associated with the more abundant minerals of this rock are pyrite and a radial variety of scapolite. The extent of ore of a particular richness seems here to be limited by vertical joint planes—hence presumably faults of small displacement. This feature is brought out in Pl. IV, *A*, which is a view of the main mine opening. In this opening the lowest floor of the pit limits by its vertical bounding planes the space from which the richest scheelite ore thus far obtained at the mine has been removed.

At the lower opening of the mine, which is located just above the mill (Pl. IV, *B*), the contact rock is chiefly a calcareous hornblende-garnet-pyroxene rock. In the view shown (the lower contact of the limestone bed is just below the wheelbarrow) is seen the massive and more crystalline nature of the limestone as it approaches the contact, and also, in the darker lenticular patches within this zone, the nodular masses of deep-red garnet rock.



A. VIEW OF THE MINE OPENING AT THE SUMMIT OF LONG HILL.

The floor is at the contact of the limestone which formed the original surface with the underlying hornblende-gneiss. The old shaft is the original opening of Lane's mine. The depressed area having rectilinear boundaries (faults) shows where the scheelite gangue rock has been removed.



B. VIEW OF THE LOWER OPENING AT THE LONG HILL MINES, NEAR THE MILL.

The crystalline limestone is filled with metamorphic minerals, and dips at a low angle to the north.

In the southern part of the main opening at the summit of the hill and in the northern part of the lower opening near the mill, the limestone and the contact rock are alike much stained with oxide of iron, an effect which appears to be connected with greater minor fracturing; and it is at just these localities that the wolframite pseudomorphs and the wolframite-scheelite intergrowths have been found. Large nodules of botryoidal marcasite, small vein fillings of the same material, and cubo-octahedrons of pyrite, which on the surface are changed to limonite, have also been found here.

An occurrence of some interest, because so far removed from the mining property, is that on the Burnett place, which is east of the road that runs north and south and is about a half mile distant in a northeasterly direction. The locality is at the lower contact of the limestone belt, which at this point dips to the westward, and the minerals found are similar to those that occur at the mine, viz, hornblende, scapolite, fluorspar, chalcopyrite, and in addition a trace of malachite. Wolframite crystals have been reported from this locality, and there is no reason to suppose that they have not been found here, although the writer was unable to discover any in his examination.

FORMATION OF WOLFRAMITE AFTER SCHEELITE.

The scheelite of the Trumbull mine, while always crystalline and in the larger specimens exhibiting its characteristic cleavage, rarely shows more than one or two good bounding planes. Perfect crystals, which are occasionally found, exhibit either the second order pyramid, *e* (101), alone or this form giving the habit to the crystal but modified by combination with one or more of the first order pyramids and the third order pyramid, *s* (311). Inasmuch as the wolframite of the locality always occurs in the form of scheelite and is clearly pseudomorphic after it, the forms are better studied on wolframite crystals. These show several types, of which the most common is probably the unmodified pyramid *e*. Next in order of frequency is the combination of the forms *e* (101) with *c* (001), *o* (102), *p* (111), and *s* (311), to which the forms *e* and *o* give the habit. Warren[1] has recently figured one of these crystals, but he has apparently fallen into the common error of giving for the paragenesis of this mineral the associated minerals of the Monroe instead of those of the Trumbull locality.

The distorted crystals and aggregates of wolframite, the latter sometimes nearly as large as the fist, are rarely found to be compact throughout, but either to have a spongy texture or to be composed in part of scheelite. Occasionally these latter specimens show a rather marked division into scheelite and wolframite portions, but more generally the two minerals are most intimately intergrown, the wolframite penetrating the scheelite in a delicate ramifying network.

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[1] Mineralogical notes, by C. H. Warren: Am. Jour. Sci., 4th series, Vol. XI, 1901, p. 373.

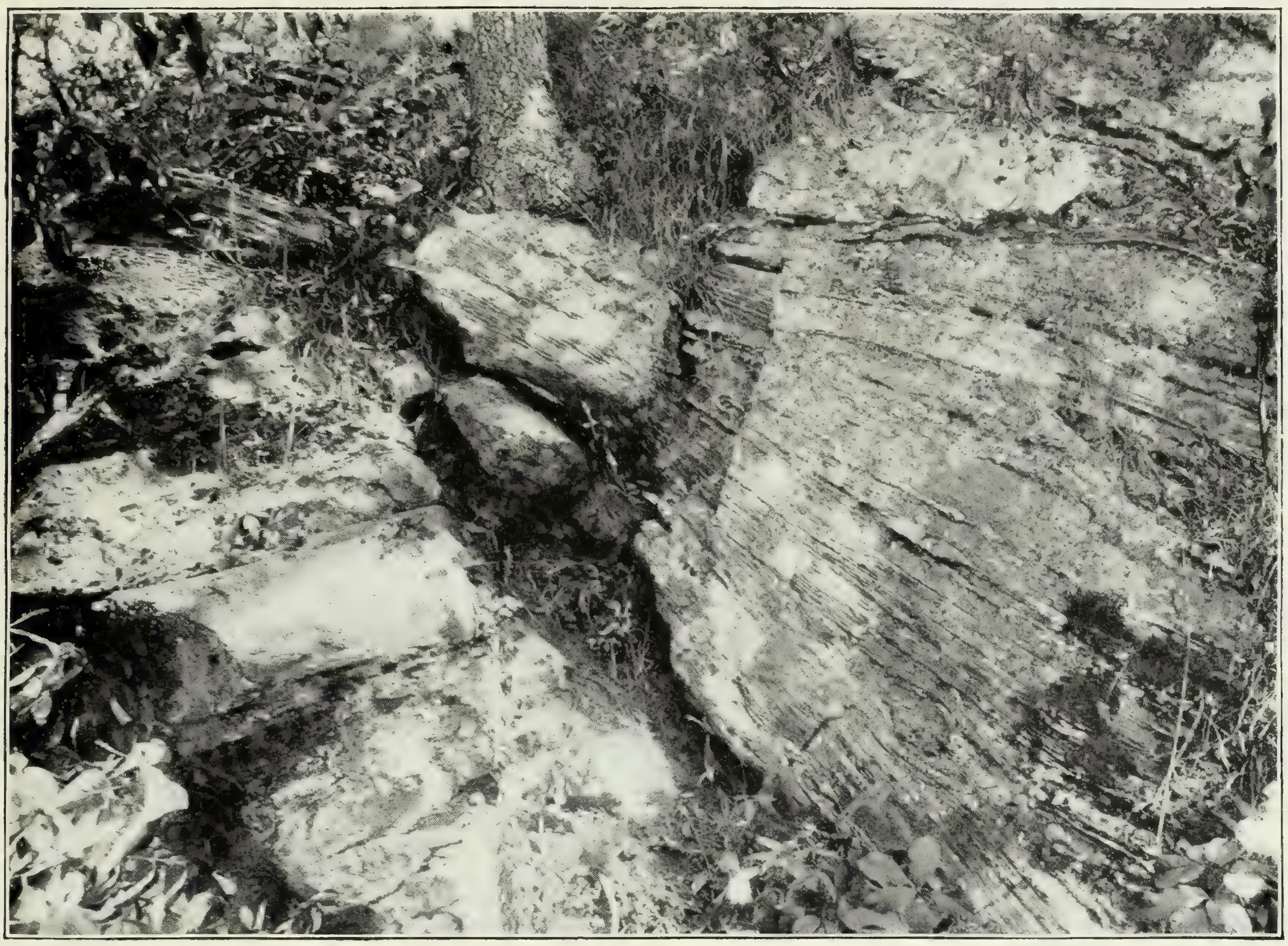
The alteration process which has changed the scheelite to wolframite has not always stopped at this point, for rusty masses of material are found associated with the wolframite, in which well-preserved pseudomorphs of limonite and wolframite after scheelite are obtained, apparently indicating that the process of introducing iron to the scheelite began by the replacement of the lime and ended by driving out the tungsten as well. As already pointed out, the wolframite is found in those parts of the contact rock that are stained by oxide of iron, a feature which seems generally to be connected with excessive fracturing.

THE VEINS.

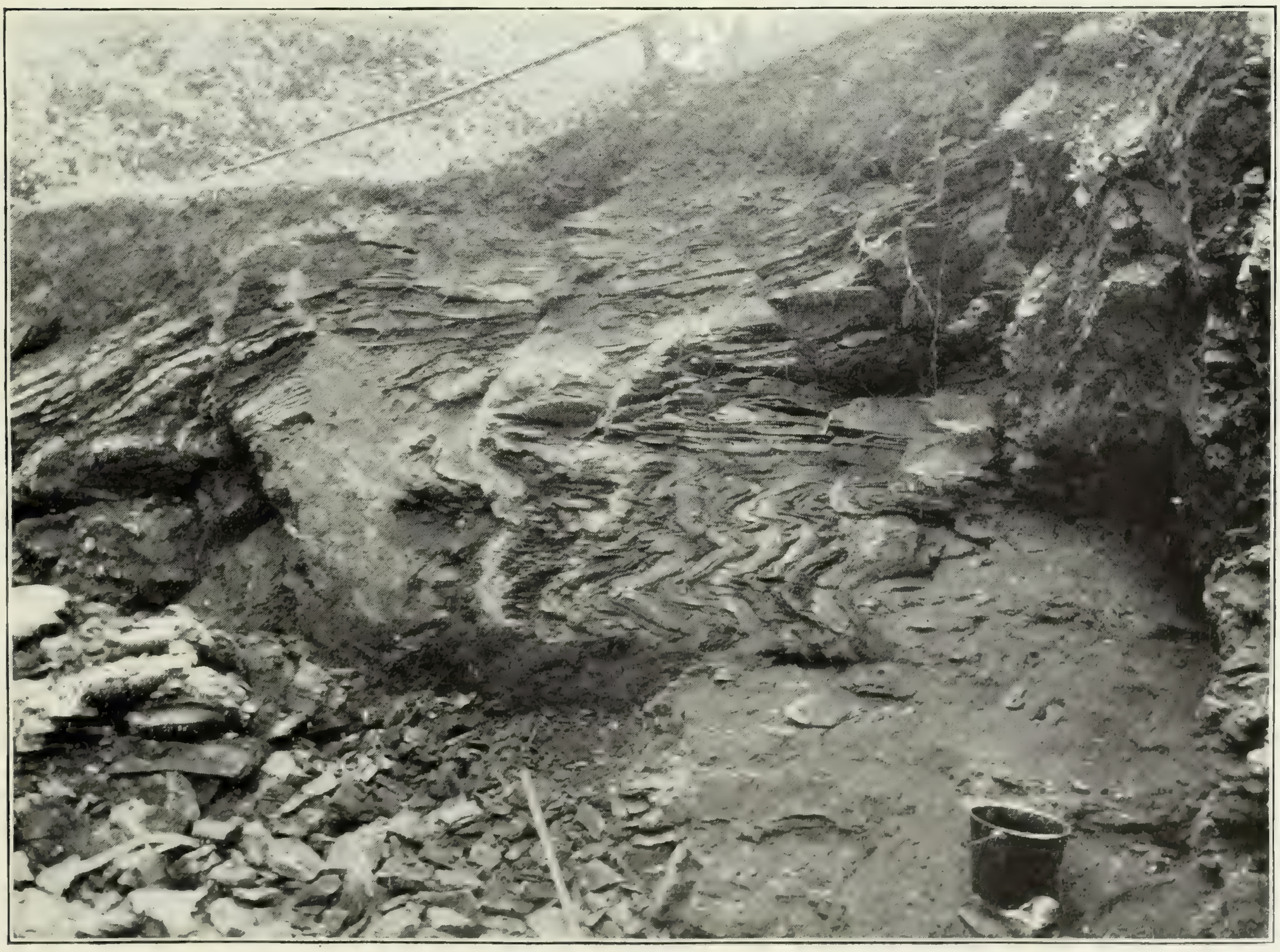
The region in which the Trumbull mine is located is one of numerous pegmatite veins. Just east of the mining property, but in the limestone belt, is a great mass of pegmatite which has been opened for feldspar and which rises from the Pequannock River in a wall 60 feet in height. At the top of the hill and near the saddle south of the mine are several veins, while others occur just below the office and near the bottom of the lower mine opening at the mill. Elsewhere, as indicated on the map, there are veins of quartz from 1 to 5 feet in width, having apparently vertical walls and a course in right lines or in zigzags composed of straight elements, a peculiarity which suggests the presence of intermediate fault planes. Some of these veins, as, for example, the 5-foot vein northwest of the projected tramway, is nearly pure silica and is now being mined for wood filling. Other veins, like the one near the limekiln and the one intersected by the westernmost test pit upon the hill, contain, besides quartz and the associated minerals of pegmatite, topaz in large masses and in occasional imperfect crystals, a reddish fluorspar, margarodite, etc. The same vein, with included topaz, is encountered in the brook between the Sage place and the limekiln, and also on the slope of the hill east of the former locality. It is not improbable that all the veins of the vicinity date from a single period of pegmatization of the area, the local variations being largely explained by the differences in the wall rock.

GEOLOGICAL HISTORY.

Hornblende-gneiss closely resembling the rock of the Trumbull locality is not uncommon in the larger area of the western uplands of Connecticut, and its manner of occurrence is often such as to indicate with some definiteness its igneous origin. Its occurrence as a metamorphosed product from impure limestone in other localities of the same regions is by no means disproved, though to the writer the evidence has seemed to point strongly to an igneous origin for practically all the areas of hornblendic rock. The masses at the Trumbull mine, however, by reason of their perfect conformity to the bedding plane of the thin intercalated limestone formation, seemed on the evidence of the field study rather to favor the view that they were parts of one



A. FAULT IN LIMESTONE IN THE WOODS TO THE EAST OF THE LONG HILL MINING PROPERTY.



B. FAULTS IN LIMESTONE AT MAIN OPENING ON SUMMIT OF LONG HILL.

The crumpling of the limestone along the fault plane is strongly marked.

mass, though against this view are the rather sharply outlined contact planes and the modified contact zones. The petrographic study of the thin sections, however, seems to the writer to prove conclusively that both beds of hornblende rock are of igneous origin, and that the interesting zones of contact are due to the action of solutions, which, with the favorable conditions of heat and pressure, so generally play a part at the boundaries of intruded magmas.

It is assumed that the igneous mass which produced the hornblende rock found planes of least resistance to its intrusion along the upper and lower contact planes of the limestones with the schists, and was in consequence injected at these planes. The great sensitiveness of limestone to the influence of adjacent igneous masses has preserved the record in an altered zone some feet in width bordering each contact. The contacts with the schists are not exposed, and, from the evidence of other localities in the same general region, would hardly exhibit altered marginal zones should they be uncovered.

MINING OF ORE.

The companies which have managed the mining property have carried out somewhat extensive operations at the summit of the hill and also near its southwestern base. They have also expended large sums in the construction of buildings and the installation of machinery. According to reports furnished by the companies, they have spent for all purposes a sum in excess of $60,000. At this writing (June, 1901) operations have been discontinued, with little prospect of resumption of work in the near future. Not more than a ton or two of pure scheelite seems to have been produced, though some unpicked material has been collected in dumps.

The method of mining at the summit opening has been to remove the upper bed of hornblende-gneiss along the gentle easterly dipping contact plane from the point where it outcrops at the surface (see Pl. IV, *A*). At favorable localities the pit has been sunk for a farther distance of a few feet in order to remove the scheelite-bearing contact rock just below this floor. The larger blocks obtained by blasting are broken with sledges and the picked ore is removed to the mill by gravity methods. Drilling is carried on by compressed air drills, the air being transmitted by pipe and hose a distance of about 1,500 feet.

The mill is built on the steep incline near the southwest base of the hill and is connected by a spur with the tracks of the Bridgeport division of the New York, New Haven and Hartford Railroad (Pl. I). The writer is indebted to Mr. W. R. Hinsdale, the vice-president and general manager of the company, for much of the detail in the following description of the milling plant in which the scheelite is separated from the gangue.

The machinery installed consists of a Blake crusher (15 by 24 inches) with a capacity of 10 tons per hour. The crusher, which with the other pulverizing machinery is actuated by a high-speed, 200-horsepower engine, discharges its product on the end of the picking table, an endless rubber belt 3 feet in width acting as carrier and feeder to two small crushers on the floor below (see fig. 1). These crushers deliver their product to two corresponding sets of Cornish rolls running one-fourth inch apart and having a 22-inch diameter and 16-inch face. These rolls discharge the material to an endless-belt elevator, which carries it to the top of the mill and delivers it to a pair of revolving screens 36 inches in diameter and 8 feet in length. These screens have wire meshes $\frac{1}{8}$-inch square, and hence refuse most of the pulp. A considerable portion of the dust is here drawn out by a current of air which passes under the screens. The portions of the material refused by these screens are carried by gravity to a pair of belted high-speed rolls of 30-inch diameter and 18-inch face, running one-eighth inch apart, and are from them returned to the elevator and again passed through the screens. After this second screening the material passes to a pair of Wolf gyrating screens of three sizes (meshes 40, 60, and 90).

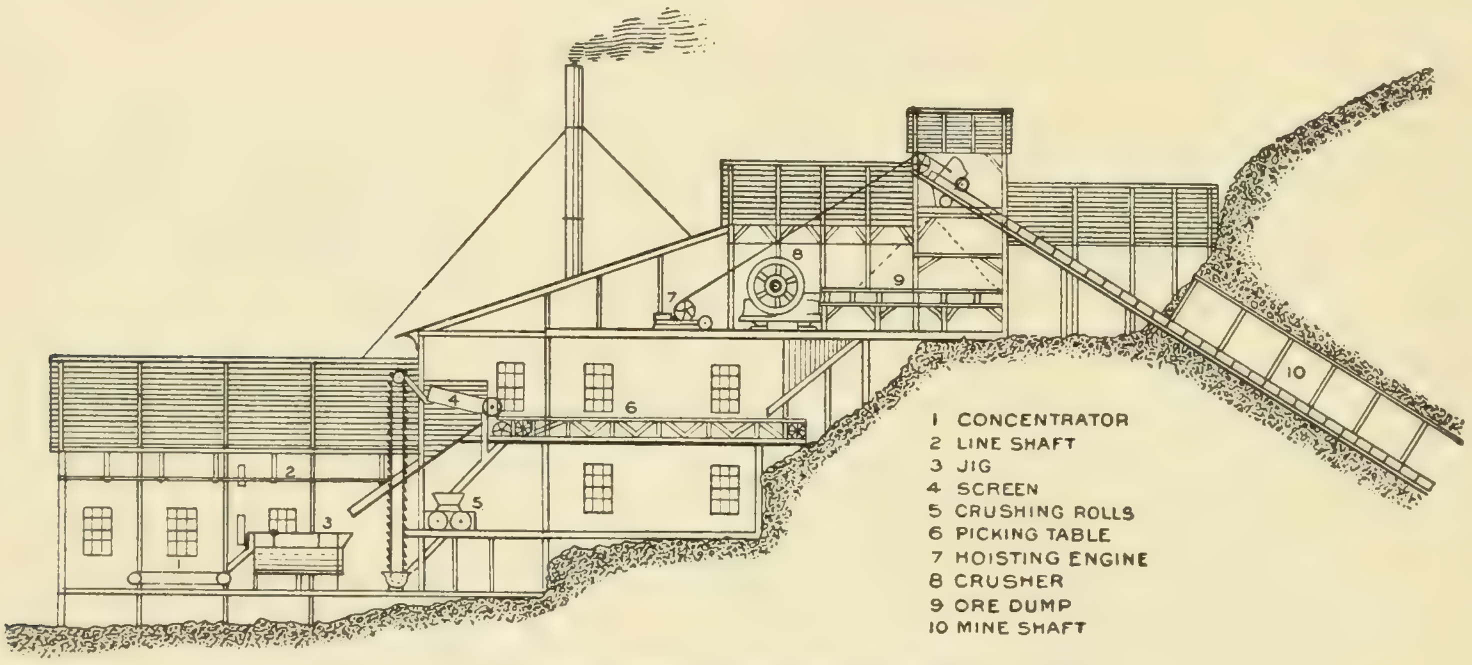


FIG. 1.—Diagram showing sectional elevation of mill.

Concentration is effected by a dry process in what is known as the Hooper pneumatic concentrating machine, which delivers the concentrates clean and leaves little scheelite in the tailings. Each machine is said to be capable of treating approximately 10 tons of pulp per day, and the yield of pure concentrates is reported to average 5 per cent by weight of pure scheelite. The scheelite as it comes from the mill is contaminated with a small percentage of pyrite, which must be removed by roasting. No attempt is made at the mining plant to separate the lime so as to change the mineral to tungstic oxide, in which form it is usually quoted in the market. Indeed, no appreciable quantity of the product appears to have been placed upon the market. The concentrating machinery is operated by a separate engine from that which runs the crushing machine.

PRELIMINARY REPORT ON THE LEAD AND ZINC DEPOSITS OF THE OZARK REGION

By H. F. BAIN

WITH AN INTRODUCTION

By C. R. VAN HISE

AND CHAPTERS ON THE PHYSIOGRAPHY AND GEOLOGY

By GEORGE I. ADAMS

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LETTER OF TRANSMITTAL.

Department of the Interior,
United States Geological Survey,
Washington, D. C., May 1, 1901.

Sir: The following report is made in response to a call for a prompt preliminary statement concerning the lead and zinc ores of the Ozark region. The economic work leading to this report was placed in the charge of Mr. C. R. Van Hise. Mr. H. F. Bain, who had investigated the lead and zinc district of Iowa for the Survey of that State, was engaged to make the economic surveys and to prepare a report upon the economic phase of the subject. The areal work in the Ozark region was in charge of Mr. Bailey Willis. Mr. G. I. Adams was engaged to carry on the detailed areal surveys.

The introduction to the report, on the genesis of the lead and zinc ores of the Mississippi Valley, is by Mr. Van Hise. Chapter I and Chapters IV to IX, inclusive, on the ore deposits of the Ozark region, were prepared by Mr. Bain, under the supervision of Mr. Van Hise. Chapter II, on the physiography, and Chapter III, on the geology of the Ozark region, were prepared by Mr. Adams, under the direction of Mr. Willis. It is, however, to be noted that there was cordial cooperation between all of the persons employed. The work, both areal and economic, was begun with all four in the field. Messrs. Van Hise and Willis remained with Messrs. Bain and Adams until the general nature of the problem was comprehended. Messrs. Bain and Adams then conducted the detailed work during the summer, and after the close of the regular field season Messrs. Van Hise and Willis again visited the region with Mr. Bain.

The excellent topographic work which serves as a base for some of the maps was executed by Messrs. W. H. Griffin and Basil Duke, under the supervision of Mr. John H. Renshawe.

While it was originally proposed that this report should cover the lead and zinc districts of the entire Ozark region, and it does this nominally, the report is satisfactory only for the Southwestern district of Missouri. The work was largely concentrated upon this district because it is the one that is of the greatest economic importance. The economic work done in the other districts was only a reconnaissance. All of these districts will need to be closely studied and further work should be done in the Southwestern district of Missouri before a report of monographic character on the lead and zinc districts of the Ozark region can be prepared.

Very respectfully,

C. R. Van Hise,
Bailey Willis,
Geologists in Charge.

Hon. Charles D. Walcott,
Director U. S. Geological Survey.

PRELIMINARY REPORT ON THE LEAD AND ZINC DEPOSITS OF THE OZARK REGION.

INTRODUCTION.

By C. R. Van Hise.

The main purpose of this introductory chapter is to compare the succession of lithologic formations of the various lead and zinc districts of the Mississippi Valley, to summarize the salient points as to the occurrence of the ores common to all the districts, and, finally, to show the relation between the facts of the occurrence of the ores and the stratigraphy.

As I first applied the theory of two concentrations for the lead and zinc ores of the Mississippi Valley to the Wisconsin district, and as Mr. Bain does not treat this district at all in the present paper, I will first consider the Upper Mississippi Valley region.

ORES OF UPPER MISSISSIPPI VALLEY.

Following Chamberlin, I hold that the lead and zinc now composing the ores were widely dispersed through the Silurian limestones. I hold that the ores were first segregated in the limestones by an artesian circulation, confined above by the Cincinnati shale and below by the Trenton shales. Later the upper shale was removed by erosion, and from this time on the conditions were changed and the descending meteoric waters produced a second concentration. Thus were formed the ore deposits now mined. Professor Chamberlin does not recognize the first stage of concentration.

The following statements in reference to the Upper Mississippi Valley are largely compiled from my paper on Some Principles Controlling the Deposition of Ores:[1]

As a result of the most excellent work of the second Wisconsin survey under Chamberlin[2] and the later work of the Iowa survey,[3] we may give the descending succession in the lead and zinc districts of the Upper Mississippi Valley, as follows:

---

[1] Some principles controlling the deposition of ores, by C. R. Van Hise: Trans. Am. Inst. Min. Eng., Vol. XXX, 1901, pp. 27-177.

[2] The ore deposits of southwestern Wisconsin, by T. C. Chamberlin: Geology of Wisconsin, Vol. IV, 1882, p. 412.

[3] Lead and zinc deposits of Iowa, by A. G. Leonard: Iowa Geol. Survey, Vol. IV, 1897, p. 23.

Cincinnati shale, originally 200 feet thick (in Iowa called the Maquoketa shale).

Galena limestone, bearing organic matter, 450 feet thick.

Trenton limestone, bearing organic matter, 40 to 100 feet thick, with mean of 70 feet, having at its top an oil-bearing shale[1] "2 or 3 to several feet in thickness at points," and containing throughout its mass various shaly layers, which, however, are "quite decidedly most prevalent near the base of the formation."[2] Generally at the base of the Trenton is "a greenish-blue clay usually from 1 to 2 feet thick. The clay is very finely laminated, and consists of argillaceous and calcareous matter."[3]

St. Peters sandstone, 50 to 150 feet thick.

Lower Magnesian limestone, 100 to 250 feet thick.

Potsdam sandstone, 700 to 800 feet thick.

Pre-Cambrian.

It is to be noted that the Galena limestone is bounded by shales above and below, and that the same statement applies generally but not universally to the Trenton limestone. It is well known that shales are impervious to underground water circulation. As to the impervious character of the thick Cincinnati shale above the Galena there is no doubt. One might, however, question the imperviousness of the thin beds of shale at the top and the bottom of the Trenton, but that the upper at least is relatively impervious is indicated by the fact that in the Shullsburg and other districts, as pointed out by Blake,[4] the ore deposits frequently stop at the top of this layer. While the impervious shales of the Trenton are prominent at the top and near the bottom of the Trenton limestone, there are more or less impervious layers within the limestone.

The strata dip to the southwest. Chamberlin says for Wisconsin:

> The strata on the north side of the lead region are 500 feet higher than those of the south side, and if traced farther the difference in altitude would be found greater. Beds on the eastern side are 350 feet higher than those on the west side.[5]

Superimposed upon the general southwest monocline of the district are a number of subordinate anticlines and synclines, and the ores, according to Chamberlin, are confined mainly to the synclines.[6]

The rocks are traversed by two complex systems of intersecting vertical joints, and in some places by more. Locally minor faulting also occurs. The folding and the fracturing of the brittle limestone were simultaneous processes. But during the deformation the plastic shales were mainly flexed, although in places they may have been dissevered by faulting. The time at which the deformation occurred is not definitely known, but in all probability it antedated the deep erosion and the concentration of ores in the district.[1]

---

[1] Blake: Bull. Geol. Soc. America, Vol. V, pp. 28–29; also Trans. Am. Inst. Min. Eng., Vol. XXII, pp. 629–632.

[2] Chamberlin: loc. cit., p. 409.

[3] Geology and topography of the lead regions, by Moses Strong: Geol. of Wisconsin, Vol. II, 1878, p. 643.

[4] Lead and zinc deposits of the Mississippi Valley, by Wm. P. Blake: Trans. Am. Inst. Min. Eng., Vol. XXII, 1894, pp. 629–632. (Discussion of Jenney's paper.)

[5] Chamberlin: loc. cit., p. 422.

[6] Ibid., pp. 432–438.

Areally the ores occur to a much greater extent east of the Mississippi River than west of it; that is, mainly east of the principal line of drainage. As to horizons, by far the greater quantity of ores which have yet been abstracted is found in the Galena limestone.[2] However, considerable amounts of ore have been taken from the Trenton, and subordinate amounts from the St. Peters sandstone and the Lower Magnesian limestone. The ores occur in the Galena from the top to the bottom.

In cases where erosion has not cut deep into the Galena, the ore deposits are apt to be found near the overlying Cincinnati shale. For instance, in Iowa, where the shales are close at hand as a continuous formation, Leonard states that the ore occurs "mostly near the top of the Galena limestone, within the upper 50 or 60 feet."[3] Where the drainage lines have cut through the Galena into the Trenton or lower formations the ores of the Galena are likely, in large measure, to be near the bottom of the formation, and considerable bodies may rest upon the oil rock which marks the beginning of the Trenton.

The broad facts as to the occurrence of the ores in the limestones are as follows:

In openings in limestones, lead and zinc minerals are associated with marcasite, and some pyrite and chalcopyrite.[4] Calcite is an abundant gangue mineral, as would be expected, but this and the other gangue minerals will not here be taken into account. Since the pyrite and chalcopyrite are very subordinate, they will not again be alluded to. All of the sulphide of iron will be referred to as marcasite.

The vertical order of occurrence in the district is commonly as follows: Above the level of ground water in the belt of weathering the dominant valuable minerals are galena and smithsonite. Frequently encrusting the galena, or in crystals upon it, there is some cerussite, and less anglesite; with the smithsonite there is some sphalerite. The smithsonite may locally occur to some extent to a depth as great as 15 to 30 feet below the level of ground water; but deeper the oxidized products almost wholly disappear. The smithsonite below the level of ground water is explained (1) by the material being often along a main channel of downward percolating waters; (2) by the fact that the level of ground water is probably now higher than it once was, as a result of depression and valley-filling at the close of the Glacial epoch; (3) by the well-known general downward movement of oxidizing water somewhat below the level of ground water, and (4) by reactions between oxidized lead salts and the sphalerite. Below the galena and smithsonite, i. e., mainly below the level of ground water, is sphalerite, with a large amount of marcasite.

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[1] Lead and zinc deposits of the Mississippi Valley, by W. P. Jenney: Trans. Am. Inst. Min. Eng. Vol. XXII, 1894, pp. 208–209. Discussion of Jenney's paper, by Wm. P. Blake: op. cit., pp. 628–629. The ore deposits of southwestern Wisconsin, by T. C. Chamberlin: Geology of Wisconsin, Vol. IV, 1882, pp. 427, 485.

[2] Chamberlin: loc. cit., pp. 407, 457, 481.

[3] Leonard: loc. cit., pp. 43, 61.

[4] Chamberlin: loc. cit., pp. 380–393.

Where the workings have extended to a considerable depth the sphalerite is subordinate, the dominant sulphide being marcasite; but many of the workings have not been penetrated to a sufficient depth to show whether or not this is general. For much of the district the workings have not gone far below the level of ground water, and consequently only the smithsonite and galena and the upper part of the sphalerite have been exploited. But during the last few years a considerable number of mines have penetrated 35 to 70 or more feet below the level of ground water. In the deeper of these workings the sphalerite and marcasite are constantly associated and the smithsonite and the galena are practically excluded. It may be further said that the few workings which have extended below the Trenton oil rock have shown great proportional increases of marcasite.

While the above general statement is correct for the district as a whole, it must not be understood that a single sulphide occurs at a given level to the exclusion of the others. Indeed, in many cases all of the sulphides are found at the same level. Chamberlin[1] states that in the upper parts of the deposits of the Galena limestone the order of arrangement of the materials from the walls to the druse is commonly (1) marcasite and (2) galena in cubic crystals. But in many cases the marcasite has been dissolved between the galena and limestone, thus loosening the galena crystals. In some cases, also, a later deposit of marcasite coats the galena. Lower in the Galena limestone the common order from the wall to the druse is (1) marcasite, (2) ferriferous sphalerite, and (3) galena in cubic crystals. In some places there are superimposed upon this succession the following members: (4) Ferriferous sphalerite (subordinate in quantity); (5) marcasite; (6) galena in octahedral crystals (very subordinate in quantity). As a result of working some distance below the level of ground water since Chamberlin's report was published, it has been ascertained that at these deeper levels the almost universal order from the wall is (1) marcasite, (2) sphalerite, galena being very subordinate.

Following Chamberlin, I think it probable that a large part of the material of these ores was once widely dispersed through the sedimentary rocks, and especially the limestones. My conception of the probable process of concentration in the Galena limestone is as follows:

While in the Wisconsin lead district the Niagara limestone and Cincinnati shale are found only on occasional mounds, as pointed out by Chamberlin,[1] there is no question that these formations once extended over the entire district. As already noted, the Cincinnati shale is an impervious stratum. Until it was cut through by the drainage it is probable that effective concentration of the ores did not begin. When it was once cut by erosion, then, as I conceive, the main concentration history of the ore deposits began. The Mississippi River and areas adjacent were the places where the drainage was the lowest. However, these were not the places first cut through by erosion, for the difference between the level of the Mississippi drainage and the tributaries adjacent is not so great as the dip of the strata to the southwest. In all probability, therefore, the Cincinnati was first cut through, and the Galena encroached upon by erosion, north and east of the lead and zinc district. This is probable from the fact that at the present time in the lead district the Mississippi River for the most part is on the Trenton limestone and never reaches deeper than the St. Peters sandstone, while the majority of the smaller streams in the northeastern part of the lead district have cut into the St. Peters, and the headwaters of some of them, notably the Pecatonica, Platte, and Grant rivers, have cut through the St. Peters into the Magnesian; and still farther to the northeast, north of the divide occupied by the Lancaster branch of the Chicago and Northwestern Railway, the strong Wisconsin has cut down to the Cambrian.[2]

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[1] Loc. cit., pp. 491–497.

It is to be remembered that the previous strata overlain by impervious strata along the Mississippi River bear water under pressure, as is shown by numerous artesian wells. The feeding area is the higher ground to the northeast. It is highly probable that the broken and consequently porous Galena limestone was a formation which was capable of carrying water to considerable distances, and in considerable quantities, although probably not comparable in these respects to the St. Peters or Potsdam sandstones. The lead and zinc district of Wisconsin is almost wholly south of the divide between the Wisconsin River and the tributaries of the Mississippi. When the Wisconsin drainage north of the divide had cut through the Cincinnati shale, this furnished a feeding area to the Galena limestone. When later the Mississippi tributaries south of the divide had cut through the Cincinnati shale into the Galena, the waters entering to the northeast and following along the limestone were able to escape to the southwest.

As erosion continued, the area in which the Cincinnati was cut through and the Galena was penetrated gradually extended to the southwest until the Mississippi itself had cut through the Cincinnati. During this time the water entered the Galena limestone at the higher elevations, that is, to the north and east, followed along this formation, and escaped at some lower point toward the Mississippi River.

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[1] Loc. cit., pp. 410–412.

[2] See Atlas of the Geology of Wisconsin, Pls. I and VIII.

While the water to the greatest extent followed the upper portion of the Galena, it is believed that this broken formation and, to an unknown extent, all the lower sedimentary formations were searched to their deepest parts, according to the laws of flowage of underground water summarized in my general paper on ore deposits already referred to.

It is well known that during the early part of the journey of underground waters they contain oxygen and, therefore, produce an oxidizing effect upon the compounds with which they come into contact. Also, when the waters first enter the ground they contain no salts in solution, and are, therefore, dissolving waters. Waters which have had a long underground journey are likely to be reducing. This is especially likely to be true if they are shut off from the surface by impervious strata. For instance, the artesian waters in the vicinity of Lake Michigan and along the Mississippi River, the feeding areas for which are central Wisconsin, are "marked by slightly sulphureted waters."[1]

Concerning the circulation, it is here sufficient to say that the meteoric water entering the earth at innumerable points occupies the entire available cross section in its journey. In the early part of its course, where it is widely dispersed, its vertical component is downward. This component is superimposed upon a lateral component, giving resultant curved lines of flow. As the water continues its journey it is more and more converged into trunk channels. In the latter part of its journey in these trunk channels the vertical component is upward. The lateral component of the journey is frequently a hundred or more times as great as the vertical component. Finally the upward component of the water in the trunk channels carries it to the surface, where it escapes.

In the Wisconsin limestone the trunk channels through which the water mainly escaped were joints. These joints in the district are called "crevices." As already noted,[2] in many parts of the district the crevices occur in two intersecting sets, and at such places of intersection it is well understood by the mining men that the ore deposits are likely to be unusually rich. In the early part of the journey, where the water was recently from the surface and was widely dispersed, it has been seen that the waters were oxidizing and dissolving. The conditions were, therefore, favorable to the oxidation of minute dispersed sulphides of lead and zinc to sulphates. Once oxidized, these metals were taken into solution, for zinc sulphate is very soluble, and lead sulphate, while considered insoluble in the laboratory because at 15° C. only about 1 part in 31,000 is dissolved in pure water, is amply soluble so far as the transfer and concentration of lead by underground waters are concerned. It is probably very uncommon for the ore-bearing solutions of the first concentration to carry so much of the metal as 1 part in 100,000.

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[1] Chamberlin: loc. cit., p. 547.

[2] Atlas of the Geology of Wisconsin, Pls. XXXVIII, XXXIX, and XL.

While the lead and zinc have been supposed to be carried as sulphates, this is not a necessary supposition, for they may have been transported in part or in whole in other forms. The dissolved lead and zinc were largely carried to the trunk channels or their vicinity. Here, where the water was ascending, it is believed that the lead and zinc were largely precipitated as sulphide.

The precipitation of the ores in and adjacent to crevices is believed to have been due to the mingling of solutions adjacent to these trunk channels. Portions of the solutions furnished the dissolved compounds. Such solutions would be likely to be those which in the latter part of their journey utilized the large opening and which had not come into intimate contact with strata bearing abundant organic material. Other solutions which in the latter part of their course came from limestone or shales containing organic matter were reducing and probably contained sulphydric acid, since, as already noted, the deep artesian waters of the present circulation of the region contain this compound. Other reducing compounds may have been carried in the waters. The mingling of these two classes of solutions in the trunk channels would throw down the lead and zinc as sulphide according to the following equations:

$$PbSO_4+H_2S=PbS+H_2SO_4.$$
$$ZnSO_4+H_2S=ZnS+H_2SO_4.$$

It is probable that at the time of this first concentration in the crevices there was a tendency for the sulphides to be thrown down in a more or less definite order across the openings, as indicated by the phenomena of crustification, although this is probably largely explained by a later concentration.

However, sulphates of lead and zinc in the solutions dispersed through the smaller openings of the rocks were doubtless in part reduced by the direct action of the organic material contained in the shales and limestones. In this case the precipitated lead and zinc sulphides would be disseminated through the shale and limestone. They would be likely to be most abundant in shales and limestones containing organic matter adjacent to a trunk channel which furnished an abundant supply of metals, for a vigorous circulation is necessary to furnish a large supply of metals, and from the trunk channels waters would continuously make their way into the adjacent carbonaceous rocks. In the lead and zinc district of Wisconsin ores are now frequently found in so-called clay openings. These clay openings to a considerable extent represent shaly layers interstratified with the limestone, once containing carbonaceous material. Thus the inference of the precipitation of the disseminated ores by the carbonaceous material is confirmed.

In the Wisconsin district iron salts were far more abundant than lead and zinc salts, as is shown by the very abundant associated iron sulphide. The process of transportation of the iron and precipitation as sulphide is precisely analogous to that of the zinc and lead.

The process above outlined continued for many centuries, perhaps for a geological period or more. By it there were finally locally concentrated along the crevices and disseminated through the limestones and shales adjacent to the crevices considerable quantities of lead and zinc sulphides associated with marcasite.

As erosion slowly progressed the zone of rising and escaping waters slowly migrated from the northeastern part of the lead and zinc district to the southwestern part. The circulation within the Galena limestone at a given time is roughly represented by fig. 2, a northeast-southwest section. The surface of the country is shown by A, A′, A″, in which A, A′ is the cross section of a northwest and southeast belt where waters enter, and A″ is in a parallel belt to the southwest in which the waters escape. The numerous curved lines below the Cincinnati shale are intended to represent the general lines of movement of the waters. The widely dispersed downward-moving lateral-moving waters, in the early stages of their journey, were oxidizing and dissolving waters. The upward-moving waters in the trunk channels (A″ B′) were precipitating waters, and the material was especially likely to be precipitated where the waters came in contact with abundant organic material.

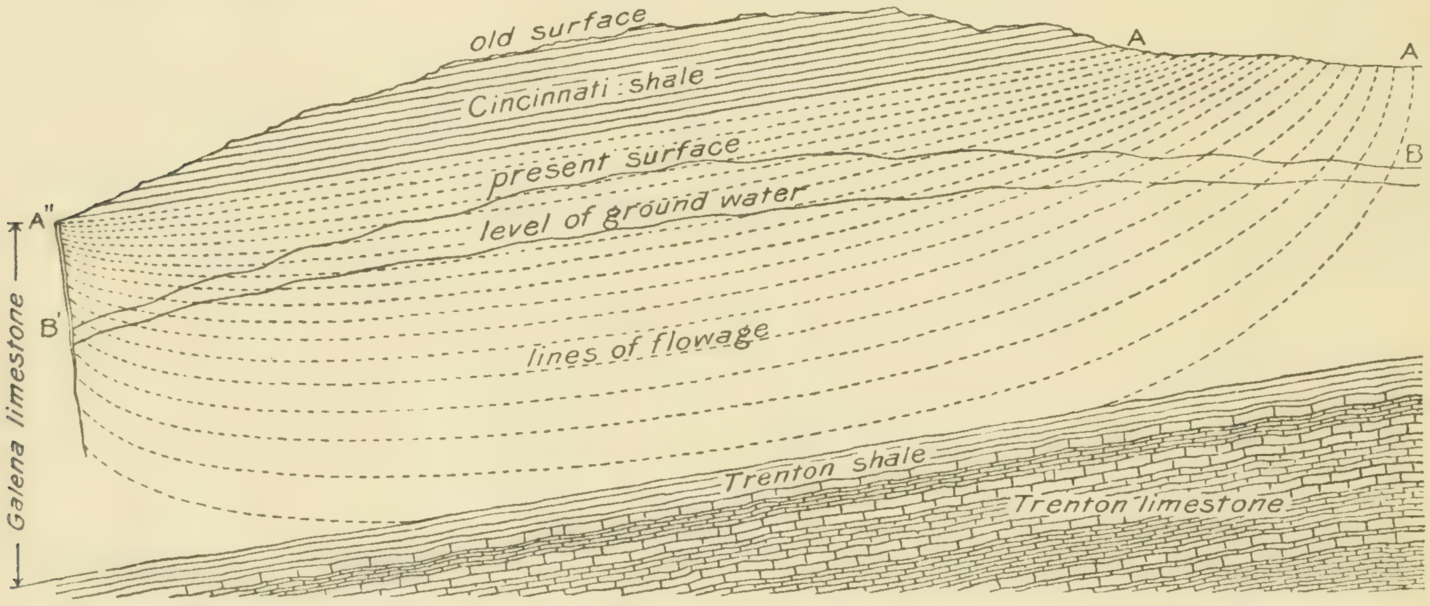

FIG. 2.—Theoretical northeast-southwest section of the lead and zinc district of Wisconsin.

The circulation was much more complex than shown by fig. 2. The circulation was not wholly delimited below by the Trenton shale. The water in its underground journey encountered not one crevice but many crevices; moreover, these crevices were in intersecting sets. The movement of the water was largely controlled by these fractures, and thus the deflections resulting from them were extremely complex. However, it is believed that the figure represents the average movement of the water in the Galena limestone. The transference of the ore material at this time was, indeed, exceedingly complex, but by the combination of all the factors considered the material was precipitated where the water was ascending in and adjacent to the trunk channels to a much greater extent than elsewhere. In an early stage of the first concentration by ascending waters the process took place only in the northeastern part of the district, for only in that part was the Cincinnati shale cut through and the porous Galena limestone exposed so that the water was able to escape. From the northeastern part of the district the process extended to the southwest as fast as the shale was here and there cut through by the streams.

SECOND CONCENTRATION.

By the time that erosion had cut through the Cincinnati shale into the Galena limestone in the southwestern part of the district and ascending waters were concentrating ores, the northeastern part of the district may have been a feeding area where waters were descending and where a second concentration was taking place. Therefore the second concentration by descending waters was probably going on in the northeastern part of the district at the same time that the first concentration by ascending waters was occurring to the southwest. At the present time the erosion has cut sufficiently deep so that the second concentration by descending waters has extended quite to the Mississippi River, and, indeed, to the west of it. At the present time the condition of affairs as to the exposures of the formation is represented by fig. 2 below the line B, B′, which may be taken as the present surface of erosion.

This general statement as to the order of events concerning the district as a whole would also apply to the local anticlines and synclines. Other things being equal, erosion would first cut through the Cincinnati shale where there were anticlines, and there water would make its way into the Galena formation. Later, when erosion had cut deep enough to expose the bottoms of the adjacent synclines, there the water entering at the anticlines arose and escaped, and a first concentration occurred in the synclinal areas Still later, when erosion had cut deeper, a second concentration by descending waters occurred; and thus these concentrations were localized in the synclines, where, according to Chamberlin, they now occur. In this connection it is to be remembered that the anticlines and synclines of the district are very gentle. Therefore the conditions are here different from those of a district where there are sharp, strongly pitching folds covered by impervious strata. So far as there are local faults, these would assist in a similar manner in both the first and second concentrations.

While it is possible that the vertical order of occurrence of the minerals is to some small extent due to a first concentration, it is believed that the controlling factor in the regular vertical distribution of the galena, smithsonite, sphalerite, and marcasite was the second concentration by the action of descending waters in connection with denudation.

The smithsonite above and a short distance below the level of ground water is believed to be derived from sphalerite, and the anglesite and cerussite from galena. It is well known that when sulphides which in the past were below the level of ground water get above the level of ground water as the result of denudation, the processes of oxidation, carbonation, hydration, and solution, characteristic of the belt of weathering, take place. Lead sulphide (PbS) and zinc sulphide (ZnS), by simple oxidation, are changed to lead sulphate ($PbSO_4$) and zinc sulphate ($ZnSO_4$). The lead sulphate, when precipitated, constitutes the mineral anglesite. If this sulphate reacts upon calcium carbonate, lead carbonate and hydrated calcium sulphate are produced, according to the following equation:

$$PbSO_4 + CaCO_3 + 2H_2O = PbCO_3 + CaSO_42H_2O.$$

In this manner the cerussite is formed. If the zinc sulphate reacts upon calcium carbonate, smithsonite is produced, according to the following reaction:

$$ZnSO_4 + CaCO_3 + 2H_2O = ZnCO_3 + CaSO_42H_2O.$$

It is a notable confirmation of the correctness of these reactions that gypsum ($CaSO_42H_2O$) is a common associate of cerussite and smithsonite.

The reactions in the belt of weathering will not here be further discussed, for it is my special purpose to explain how descending waters acting upon a first concentration of sulphides may concentrate galena at high levels, produce a mixture of galena and sphalerite at intermediate levels, and sphalerite and marcasite at the low levels. It is of course understood that at all levels the marcasite is present. If it be premised that the ascending waters evenly distributed the sulphides, at least so far as the vertical element is concerned, it is certain that downward-moving waters, combined with denudation, may concentrate the galena at high levels and the sphalerite at lower levels.

GALENA.

Under surface conditions galena is the most difficultly oxidizable of the three sulphides of lead, zinc, and iron. It is therefore the most stable of them. By the oxidation of the sphalerite and marcasite to sulphates above the level of ground water and the solution of these soluble compounds the galena would be concentrated by abstraction of associated material. That this process has taken place on an extensive scale is shown by the occurrence of many detached fallen crystals and masses of galena in the openings above the level of ground water. Indeed, a considerable portion of the lead of the district which has been taken above or within a few feet below the level of ground water strongly corroborates the idea of concentration as a result of the oxidation and solution of the other sulphides which held the galena to the walls, thus permitting the material to drop to lower positions in the crevices. This process of concentration, while important and the most obvious, works upon material already secondarily enriched by chemical concentration, as explained in the following paragraphs.

While the concentration of the galena is partly explained by the abstraction of other constituents, it is more largely explained by chemical reactions between the descending solutions and the compounds with which they come into contact. Above the level of ground water, as already noted, the galena is continuously oxidized, as shown by the corroded crystals and by the incrustations and superimposed crystals of anglesite and cerussite upon the galena.[1] During the formation of these sulphates and carbonates of lead a portion of these salts is taken into solution and carried downward. These sulphates and carbonates react (1) upon the other sulphides present, and (2) upon the organic matter with which they come into contact, and reprecipitate the lead as galena. These reactions take place to some extent above the level of ground water, but are especially likely to occur below that level. As a result of the downward migration of the belt of weathering, there is in the downward-moving waters a continual supply of the sulphates and carbonates of lead. The chief reaction is that between the lead salts and the dominant iron sulphide. Supposing the iron to be in the form of FeS, the reactions may be written as follows:

$$PbSO_4+FeS=PbS+FeSO_4.$$
$$PbCO_3+FeS=PbS+FeCO_3.$$

If the iron be supposed to be in the form FeS_2, as is most likely, oxygen also is necessary for the reactions. The equations are then as follows:

$$PbSO_4+FeS_2+O_2=PbS+FeSO_4+SO_2.$$
$$PbCO_3+FeS_2+O_2=PbS+FeCO_3+SO_2.$$

However, it has been premised that with the sulphide of iron of the first concentration zinc sulphide is associated, and this may also react upon the lead salts, according to the following reactions:

$$PbSO_4+ZnS=PbS+ZnSO_4.$$
$$PbCO_3+ZnS=PbS+ZnCO_3.$$

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[1] Chamberlin: loc. cit., pp. 453-498.

In the case of the latter reaction smithsonite is formed. In this connection it is notable that smithsonite is frequently associated with galena for some distance below the level of ground water. While a part of the smithsonite below the level of ground water is of this origin, doubtless the larger portion of it may be differently explained.

The reactions of descending solutions bearing oxidized products upon low-grade sulphurets, producing rich sulphides of lead, have been dwelt upon, but it is not supposed that these are the only reactions which have resulted in enrichment. As pointed out by Chamberlin,[1] organic matter has made its way into the openings of the limestone, and as further indicated by Chamberlin,[2] and emphasized by Blake,[3] organic matter is abundant in certain of the shaly layers. As has been held by Chamberlin and Blake, organic material in the rocks from both of these sources was probably an important factor in the reduction and precipitation of the downward-moving sulphate.

To the foregoing reactions, partly explaining the concentration of galena, objection may be made on account of the small solubility of lead sulphate and lead carbonate. It is true that these substances are very sparingly soluble in pure water; however, they are sufficiently soluble in the waters of the belt of weathering bearing carbon-dioxide to account for the phenomenon. If this be not the case, the lead may have been carried downward as chloride. Independent, however, of chemical theory, we know that in many districts, and particularly in the lead and zinc district of southwestern Wisconsin, the galena has been changed to some soluble form upon an extensive scale. As evidence for this it may be noted that galena crystals above the level of ground water are much corroded,[4] and that the amount of cerussite and anglesite associated with them is too small to account for the corrosion, and therefore the lead has been transformed to a soluble salt, which has been transported below in important amounts.

So far as my argument is concerned as to the reactions between the oxidized products and the low-grade sulphides, it is of no consequence whether the lead in solution be sulphate, carbonate, chloride, or other salt. However, it is believed that these are the forms in which the lead is transferred on a most extensive scale, and of these salts probably the sulphate is the most important. I regard the anglesite and the cerussite, which occur in subordinate quantities above the level of ground water, as evidence of the partial transfer of the lead as sulphate and carbonate. Indeed, these compounds are evidence that their formation goes on so rapidly that the descending waters are not able to dissolve and transport all of them, and consequently some sulphate and carbonate of lead are precipitated near the places of formation.

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[1] Loc. cit., p. 544.

[2] Ibid., p. 546.

[3] Lead and zinc deposits of the Mississippi Valley, by Wm. P. Blake: Trans. Am. Inst. Min. Eng., Vol. XXII, pp. 630-631. Wisconsin lead and zinc deposits, by Wm. P. Blake: Bull. Geol. Soc. America, Vol. V, 1894, pp. 28-29.

[4] Chamberlin: loc. cit., pp. 498-499, 500.

SPHALERITE.

Zinc holds sulphur less strongly than lead, but much more strongly than iron, therefore the descending zinc compounds are concentrated in the horizon below the greater part of the galena and above much of the marcasite. Sulphate and carbonate of zinc are formed above the level of ground water. Below, these oxidized products react upon the iron sulphides, the equations being similar to those producing the galena. These may be written as follows:

$$ZnSO_4+FeS=ZnS+FeSO_4;$$
$$ZnCO_3+FeS=ZnS+FeCO_3;$$

or

$$ZnSO_4+FeS_2+O_2=ZnS+FeSO_4+SO_2;$$
$$ZnCO_3+FeS_2+O_2=ZnS+FeCO_3+SO_2;$$

or, as explained in reference to the galena, the zinc sulphate is reduced to the sulphide by the organic matter with which it comes into contact. As pointed out by Blake,[1] the evidence of the effect of the organic matter in reducing the sulphates is especially strong in the case of large sphalerite deposits which rest upon the shale at the top of the Trenton limestone as a floor. However, in this connection it should be pointed out that the position of the ores upon the oil rock is probably explained through the reducing action of secondary solutions slowly oozing up through the shale, for the ore is not mainly precipitated in the oil rock, but immediately above it; and it is to be remembered that all of the pervious strata capped by impervious strata in this district bear water under pressure, therefore water would slowly pass up through the shale, for no formation is absolutely impervious.

MARCASITE.

At a certain depth in the openings below the level of ground water nearly all of the oxidized salts of lead and zinc descending from the belt of weathering, so far as they are thrown down by sulphides, are reprecipitated by reactions between them and the iron sulphide, as above explained. But in veins in which the first concentration extends to a depth greater than this, only the sulphurets of the first concentration are found. These sulphurets consist mainly of marcasite, with subordinate amounts of sphalerite and galena. However, even in this belt, concentration of galena and sphalerite may occur to some extent, although it receives no contribution from the lead and zinc salts from above; for even after the salts of lead and zinc traveling downward from the belt of weathering are all precipitated, the waters may still hold oxygen. This oxygen would, to the largest degree, act upon the marcasite, producing soluble salts, which would be abstracted, and thus reduce the quantity of this material, and relatively enrich the deposits in lead and zinc, although not increasing the absolute amount of lead and zinc present in a given vertical distance. So far as the zinc and lead salts were oxidized by the oxygen-bearing water, the salts formed would react upon the iron sulphide again, or upon organic matter, and would be precipitated according to the reactions above given.

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[1] Loc. cit., pp. 630–632.

GENERAL CONCLUSIONS.

From the foregoing it is believed that a second concentration by descending waters explains the orderly distribution of the ores in a vertical direction,[1] although original deposition by ascending waters may have produced some effect. For the sake of simplicity, in the second concentration all the galena has been supposed to be precipitated above the sphalerite. However, if the above reasoning be correct, we may suppose that the two would overlap and that there would be an intermediate horizon in which both galena and sphalerite would be important. With this expectation the facts accord, as is seen at the Durango mines west of Dubuque. It is there seen that, so far as the sulphides are concerned, the galena occurs above, with sphalerite very subordinate; at middle horizons galena and sphalerite occur together, and at the lower horizons sphalerite is the only one of these two important minerals. Still lower marcasite is the dominant sulphide.

Furthermore, the regular lateral distribution of the minerals from the walls to the druse may be partly explained by the above reactions, although it is possible that this lateral arrangement is partly due to variations in the materials precipitated during the first concentration. It is noted that in the upper part of the Galena limestone, where lead is the only important ore, there is or has been marcasite between the galena and the walls. This suggests that during the second concentration the iron sulphide was the chief agent which precipitated the descending oxidized salt of lead. Deeper down, where the order from the wall is (1) marcasite, (2) sphalerite, and (3) galena, it appears probable that both marcasite and sphalerite were precipitating agents for the galena. Where there is a later succession superimposed upon the first, that is, (4) sphalerite, (5) marcasite, and (6) galena, the sphalerite and galena, however, being in very subordinate quantities, these minerals are probably due to comparatively late reactions. At the lower levels of mining, where the sphalerite and marcasite are dominant and the galena is nearly wanting, the marcasite was the chief sulphide for the reduction of the descending zinc sulphate to sulphide. However, it must be remembered that the sulphides were not the only reducing agents for the oxidized compounds. The reduction may have been caused to an important degree by the organic material of the shale and limestone.

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[1] Chamberlin: loc. cit., pp. 551-553.

Finally, it is believed that the second concentration by descending water was the ultimate determinative factor at most places in making the ores so rich as to warrant exploitation. This statement in reference to the rich deposits applies both to the oxidized products and to the sulphurets, both above and below the level of ground water. This process of concentration is primarily chemical, but is also to some extent mechanical, especially where galena has been loosened by solution from the walls and fallen to lower positions in crevices and caves.

My conception of the process of concentration of ores in the Galena limestone is therefore that of a circulation practically limited above by the Cincinnati shale and largely limited below by the impervious oil shale of the Trenton. To what extent ascending waters from the St. Peters, Cambrian, and pre-Cambrian rocks under the pressure of considerable head were able to work up through the more or less impervious shales of the Trenton limestone is uncertain. Where faulting has occurred sufficient to displace the thin belts of shales this would be an important help. For the purposes of this paper it makes little difference whether during the time of deposition of ores in the Galena limestones by ascending waters the circulation was practically limited by the Cincinnati shale above and the Trenton below, or a contribution of waters ascended from greater depths. For a given point where the Cincinnati shale had been cut through, the first concentration occurred by ascending waters, and later, when the Cincinnati shale was removed, the second concentration by descending waters took place. The belt of second concentrates by descending waters slowly migrated downward as erosion extended into the Galena. Where the denudation has gone a little way into the Galena the ore deposits are found near its upper part. Where denudation has gone well down into the Galena the ore deposits are found near its lower part. Where the drainage lines have cut considerably below the Galena the second concentration and downward migration of the ores have resulted in the formation of considerable deposits directly upon the oil rock at the top of the Trenton. In these cases the materials exploited are probably the second concentrates from the entire Galena formation.

It will be seen at once that the above theory of circulation explains the formation of rich deposits near the top of the Galena, as in Iowa, and these deposits are very difficult to account for solely upon the theory of descending waters. It accounts equally well for the formation of rich ores in the middle and lower horizons of the Galena, where denudation has gone further. It accounts for the much wider distribution of the ores east of the Mississippi River than west of that river, since the strata east and west of the Mississippi dip to the southwest, and west of the river the drainage has cut through the Cincinnati shale for only a narrow strip, this being an essential condition antecedent to the process of concentration as above outlined.

In the parts of the Upper Mississippi Valley where erosion has cut deeply into the Trenton, and especially where it has cut into the St. Peters, a similar history is applicable to the Trenton formation, since the Trenton has impervious beds at its top and bottom, but both of these beds are thin, and the deposits may not have been wholly derived from the Trenton formation, but probably received important contributions from the Galena formation above and subordinate contributions from below.

In the application of the foregoing it is of course understood that the action of ascending and descending waters in a given fissure is not wholly successive, but is in large measure simultaneous. In the early stages of the deposition of an ore deposit in a given fissure, ascending waters are likely to be the dominant factor; in an intermediate stage both ascending and descending waters are at work; and in the later stages of the process, and at the present time, descending waters are the dominant, and, perhaps, in the cases of many of the deposits where the oil rock of the Trenton is near the surface, almost the sole factor.

At the bottoms of valleys the waters have continued to be essentially ascending instead of descending to the present time. The fact of their present ascension Chamberlin[1] notes. Thus, in these places a second concentration has not occurred, and therefore such places are deficient in workable ore deposits, as noted by Chamberlin.[2]

These views in reference to the concentration of the ores in the Upper Mississippi Valley differ somewhat from those of Chamberlin,[3] Whitney,[4] and others, who have held that the concentration of the ores is solely the work of descending and lateral-secreting waters, but still more from those of Percival[5] and Jenney,[6] who have held that the ores were derived from a deep-seated source. Percival supposed the transportation to have taken place through aqueous, and Jenney through igneous, agencies. If my views be compared with those of the descensionists, typified by Chamberlin, and the ascensionists, typified by Jenney, it will be seen that I occupy an intermediate position. Upon the fundamental point as to whether the ores are derived from a deep-seated source or from sedimentary rocks, I follow Chamberlin, although I do not feel certain that some of the material for the ores was not derived from a deeper source.

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[1] Loc. cit., p. 565.

[2] Ibid., p. 563.

[3] Ibid., pp. 544-549.

[4] Whitney: Geology of Wisconsin, Vol. I, 1862, p. 398 et seq.

[5] Percival: First Ann. Rept. Geol. Survey Wisconsin, 1854, pp. 30-33; Ann. Rept. Geol. Survey Wisconsin, 1856, p. 63.

[6] Lead and zinc deposits of the Mississippi Valley, by W. P. Jenney: Trans. Am. Inst. Min. Eng., Vol. XXII, 1894, pp. 219-223.

The account here given of the ore deposits of the Upper Mississippi Valley is not even approximately complete. To give a satisfactory account of the genesis of the ore deposits of this district would require a detailed study and a monographic report. Such a report upon many phases of the problem—a remarkable paper—has already been written by Chamberlin.[1]

OZARK REGION OF LOWER MISSISSIPPI VALLEY.

After having worked out and published, in substantially the above form, the story of the genesis of the lead and zinc ores of Wisconsin,[2] I was directed to take charge of the investigation of the lead and zinc ores of the Ozark region. In this region are four districts: The Southwestern district of Missouri, the Southeastern district of Missouri, the Central district of Missouri, and the North Arkansas district.

SOUTHWESTERN DISTRICT OF MISSOURI.

After I had examined a number of mines in company with Messrs. Willis, Bain, and Adams in the Southwestern district of Missouri, and had studied Winslow's report in connection with the examinations made, I became convinced that essentially the foregoing explanation of the genesis of the ores was as applicable to this district as to the Upper Mississippi Valley. In the Southwestern district the descending stratigraphic succession, as given by Winslow,[3] is as follows: (1) Coal Measures shales; (2) Lower Carboniferous limestone; (3) Devonian (Eureka shales); (4) Lower Silurian.

The corresponding generalized succession of Adams contained in this report is: (1) Undifferentiated Carboniferous sandstones and shales; (2) Lower Carboniferous (Mississippian) limestones; (3) Devono-Carboniferous shales;[4] (4) Cambro-Silurian limestones and sandstones.

It is therefore clear that with a change of names the lithologic succession given in fig. 2, prepared for Wisconsin, is applicable to this district. For the Cincinnati shale there is to be substituted the Coal Measures shale; for the Galena limestone is to be substituted the Mississippian limestone; for the Trenton shale, the Devono-Carboniferous shales; for the Trenton limestone, the Cambro-Silurian limestone.

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[1] Ore deposits of southwestern Wisconsin, by T. C. Chamberlin: Geology of Wisconsin, Vol. IV, 1882, pp. 366-571.

[2] Some principles controlling the deposition of ores, by C. R. Van Hise: Trans. Am. Inst. Min. Eng., Vol. XXX, 1901, pp. 102-109.

[3] Map of the southwestern lead and zinc district of Missouri, accompanying report of Arthur Winslow on The lead and zinc deposits of Missouri: Missouri Geol. Survey, Vols. VI and VII, 1894.

[4] The Survey has discontinued the use of "Eureka" as a name for these shales, because the application of the word to the quartzites of Nevada (Eureka quartzites) has priority. The Committee on Formation Names has recommended that in this paper the general expression Devono-Carboniferous shales be used.—EDITOR.

Moreover, it is notable that the relative thicknesses are approximately similar. The Cincinnati and Carboniferous shales are both thick; the Trenton shales and the Devono-Carboniferous shales are both thin beds, and locally the latter may be almost absent, being represented by shaly limestone. However, the Galena limestone and Trenton limestone in Wisconsin are not nearly so thick as the Carboniferous limestone and the Cambro-Silurian limestone in Missouri. The dip of these strata, as shown by Winslow's reports, is away from the Ozark uplift; that is, to the west and northwest. Moreover, as in Wisconsin, the dip is steeper than the drainage lines, so that the lower beds are exposed in the high areas.

The broad facts of the occurrence of the ores in this district were found to be as follows: Above the level of ground water and for a short distance below the level of ground water are found oxidized ores and galena, precisely as in Wisconsin. A short distance below the level of ground water the galena becomes subordinate, being replaced by sphalerite. In some of the deeper mine workings, 200 feet or more—as, for instance, at Carterville—galena and sphalerite are found intermingled. Mr. Willis and Mr. Bain found that the deep borings at Granby developed pyrite as the dominating mineral. It therefore appears that, so far as the vertical distribution is concerned, all of the characteristic features are identical with those of Wisconsin. In the character of the oxidized ores there is, however, one difference. The oxidized zinc ores are partly zinc carbonate, but are also in certain places—as, for instance, at Aurora—zinc silicate. This difference is correlated with the great relative abundance of chert in the Missouri district. In the Wisconsin district chert is subordinate, and when the zinc sulphide is oxidized to the sulphate it reacts upon the calcium carbonate, producing zinc carbonate, according to the following equation:

$$ZnSO_4 + CaCO_3 + 2H_2O = ZnCO_3 + CaSO_4.2H_2O.$$

In the Missouri district chert is very abundant indeed. In the areas in which oxidized ores occur the chert has largely changed to a soft rock—which can be cut with a knife—called "tallow" rock by the miners. Evidently this is residual material from which considerable quantities of chert have been dissolved. This shows that some of the silica of the chert at the time of the ore formation was in a somewhat readily soluble form. As silica went into solution it doubtless was hydrated to H_4SiO_4, as this is the ordinary form in which silica is transported. When the zinc sulphide was oxidized to the sulphate, it would react upon the silicic acid present with simultaneous hydration, producing zinc silicate, according to the following reaction:

$$2ZnSO_4 + H_4SiO_4 + H_2O = H_2Zn_2SiO_5 + 2H_2SO_4.$$

The almost complete absence of zinc silicate in Wisconsin and the presence of zinc silicate in southwestern Missouri are in accordance with the well-known law of mass action. Where silica is abundant, so that zinc silicate can form, it is present plentifully; where silica is absent, or subordinate it does not develop in any considerable quantity.

Another important respect in which the lead and zinc district of southwestern Missouri differs from that of the Upper Mississippi Valley is in the relative unimportance of iron sulphide. The Missouri zinc ores in general do not contain much iron sulphide, and therefore have a greater market value. But at some points in Missouri the amount of iron sulphide is so great as to make the ores less salable. The explanation of this difference is, doubtless, that soluble iron compounds were more abundant in the original limestone in Wisconsin than in Missouri.

A final difference between the Wisconsin and Southwestern Missouri districts is that the patches of shale still cap many more of the areas in the Missouri district than in the Upper Mississippi Valley district. This is well illustrated at all of the important mining camps. As a consequence of this, the evidence of the two concentrations described for Wisconsin is much clearer in Missouri. In Wisconsin the second concentration by descending waters has gone so far that the first concentration by ascending waters might be overlooked. Indeed, according to Chamberlin, in 1882, and Bain, in 1897, these ores are wholly due to a single concentration by descending and lateral-secreting waters.

While some geologists may still hold that there was only a single concentration in Wisconsin, I believe that no one who examines the Southwestern district of Missouri will be inclined to hold that view. The phenomena in Missouri are particularly striking in areas where the ores are in part below impervious shales and in part at places where the shales have been removed and oxidizing waters have been long at work. While there are many localities which illustrate this, perhaps the most striking locality is Aurora. Here, over the major part of the productive portion of the camp, the shales have long ago been removed, and oxidizing downward-moving waters have transformed the ores of zinc to the silicate and carbonate upon the most extensive scale, to a depth of 150 feet or more. The evidence of descending concentrating waters is indeed very impressive, many of the mines starting in places which were practically sink holes. It was phenomena of this kind which led Winslow to believe that all of the mines are thus produced by mechanical and chemical segregation in connection with denudation. In marked contrast with these occurrences, only a mile or two distant from the silicate mines of Aurora, at the so-called Sand Ridge, a shaft passes below the Carboniferous shales (see fig. 29, p. 170), and in the cherty limestones almost immediately below these shales the unaltered sulphides are found.

Further, there is the very greatest difference in the cleanness of the two classes of mines. Where the oxidized products are worked the mines are muddy, clayey, and sticky to the last degree; the waters are full of mechanical sediment, showing that water has come in from the surface. In the sulphide mines, on the other hand, numerous beautiful clean-water channels are found, the crystal linings of which when the water is first pumped out are brilliant and untarnished. Further, the mining men unanimously agree that in the case of all of the sulphide mines in which there are clean, deep channels local precipitation produces no appreciable effect upon the amount of water to be pumped. Finally, our own observations fully confirmed the conclusions of Jenney that in Missouri the deposits are associated with belts of fracturing and displacement, precisely as they are in Wisconsin.

Combining all of these facts, which were accumulated during our first week's visit, I was irresistibly driven to the conclusion that the results which I had reached in Wisconsin were directly applicable to the Missouri deposits; that is to say, changing the phraseology of my statement concerning the Wisconsin ores so as to substitute for central Wisconsin uplift, Ozark uplift; substituting for Cincinnati shale, Carboniferous shale; for Galena limestone, Lower Carboniferous limestone; for Trenton shale, Devono-Carboniferous shale, and for Trenton limestone, Upper Silurian limestone, my Wisconsin paper was regarded as applicable almost without modification. The much more detailed facts presented by Mr. Bain in his report fully confirm this conclusion.

An important additional structural point was later developed by Bain and Adams. They showed that the faults in many cases are sufficient to cut quite across and displace the Devono-Carboniferous shales even if at their full thickness, and thus render it certain that ascending water may rise from the Upper Silurian limestone to the Carboniferous limestone. In this connection Mr. Bain has contributed a very important idea to the theory of the genesis of the ores. It is well known that the greater number of the deposits of lead and zinc in the Mississippi Valley occur in connection with the Cambro-Silurian limestone. It has been generally agreed that the source of the ores for these deposits is the widely dispersed lead and zinc of the limestone itself. In southwestern Missouri the most important deposits are in the Carboniferous limestone. Mr. Bain unifies the occurrences of the entire Mississippi Valley by showing it to be highly probable that the ores of this limestone have been brought up from the Cambro-Silurian limestone through the Devono-Carboniferous shale.

SOUTHEASTERN AND CENTRAL DISTRICTS OF MISSOURI.

After having applied the Wisconsin theory to the Southwestern district, I went over the descriptions by Winslow of the Southeastern and Central districts of Missouri, and it appeared to me highly probable that the same theory, modified to suit local conditions, explains these occurrences of ore. In the Southeastern district the descending succession is Mississippian limestone, Devono-Carboniferous shale, Cambro-Silurian limestone, pre-Cambrian crystalline rocks. While Winslow's maps do not show this, nearly all of Winslow's numerous detailed sections show shale in the lower part of the Cambro-Silurian limestone above the Cambrian sandstone.[1] In the productive areas the Carboniferous limestone and the Devono-Carboniferous shale have been entirely removed by erosion. The ore deposits of this district are in the Cambro-Silurian limestone above the shales and associated with the shales belonging in the lower part of this limestone. Finally, the rocks have a dip away from the Archean core to the Missouri and Mississippi rivers; that is, to the northwest, north, and northeast. It therefore appears that the general facts in this district are remarkably similar to those in Wisconsin. However, the names of the formations and positions are slightly different. For the Cincinnati shale of Wisconsin there is to be substituted the Devono-Carboniferous shale; for the Galena limestone, the Upper Silurian limestone; for the Trenton shale, the shale in the Cambro-Silurian limestone, not named in Missouri.

CHARACTER OF THE ORES.

As to the character of the ores, there are two distinct areas in which the occurrences are markedly different. Following Winslow's classification,[2] the first of these is the St. Francois and Madison Counties subdistrict, and the second includes the Washington and Franklin Counties subdistrict, i. e., the remainder of the Southeastern district and all of the Central district.

ST. FRANCOIS AND MADISON COUNTIES SUBDISTRICT.

The first subdistrict, that of St. Francois and Madison counties, contains the largest and most important lead mines of eastern Missouri. Winslow describes five camps in this subdistrict,[3] viz: (1) Mine La Motte, (2) Bonne Terre, (3) Flat River, (4) Doe Run, and (5) Avon. At all of these areas the ores are galena. The galena for the most part is disseminated through solid crystalline limestone, in many cases rather evenly; but in some cases, as in the Mine La Motte deposits, "grains of galena are frequently strung out along the stratification, sometimes so close together as to form sheets which vary in thickness from one-tenth to several inches."

Disseminated galena is also found as a matrix of conglomerate between bowlders at the Doe Run mines.[4] The Bonne Terre disseminated ores occur principally at two horizons. The limestone of the upper horizon is known as the "black rock" and the lower as the "white rock."[1] The ore is more persistent in the "white rock." Blende is very subordinate, and at the Bonne Terre camp "absolutely no zinc occurs, not even enough to be detected by analysis."[2] At the Mine La Motte and the Flat River areas the ore is notably rich at the lower part of the Magnesian limestone, where there are interstratified layers of slate.

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[1] Winslow: loc. cit., Vol. VII, pp. 646-676.

[2] Ibid., p. 645.

[3] Ibid., p. 646.

[4] Ibid., p. 673.

In some of the camps early workings developed concentrated deposits of galena in crevices.[3] For instance, at the Bonne Terre "near the surface concentrated deposits of galena were found in crevices, and in the days of early mining these were the principal ores worked. * * * Several such crevices were developed and worked here, but they were all found to grow narrower and to become unproductive with depth."[2] At the Flat River mines, also, "large amounts of massive galena were mined from crevices by shallow diggings." But at present the ore "consists principally of galena disseminated through Magnesian limestone," and these disseminated ores are at a greater depth than the galena in the crevices.[4] The early workings also developed considerable cerussite, as, for instance, at the Mine La Motte and Bonne Terre mines.[1] The associated ore-bearing minerals are iron pyrites and copper pyrites and cobalt sulphide and nickel sulphide. It is notable that the copper pyrites carrying workable amounts of nickel and cobalt at Mine La Motte are found in the upper of the two horizons at which the ore occurs—the "black rock" rather than the "white rock." Also at the Bonne Terre mines the copper pyrite and pyrrhotite, carrying about 4 per cent of nickel and cobalt, characterized the upper workings down to a depth of 100 feet or so,[2] "although such ores are reported as occurring at lower levels." "As in the Southwestern district of Missouri, pyrite is subordinate in quantity." Doubtless the cause is the same as in that district (see p. 51).

The chief gangue minerals are calcite and dolomite, and it is notable that barite is absent, although so abundant in the second subdistrict of southeastern Missouri and in the Central district.

The first four of these groups of mines are among the deepest lead and zinc mines of the Mississippi Valley. For instance, the ores of the Mine La Motte area are mostly found between 70 and 150 feet from the surface.[1] The richest horizons of the Bonne Terre area are between 150 and 250 feet from the surface.[2] In these two areas the crevice deposits above described were at higher levels. In the Flat River areas most of the ore is below the 150-foot level; much of it is between 200 and 300 feet from the surface, and the lower level of the Central Mining Company is 380 feet deep.[4] The Doe Run mines are principally between 50 and 90 feet from the surface, but galena has been developed to a depth of 230 feet.[1] Finally, the ores in this district are associated with zones or belts of fracturing and faulting, just as in the Southwestern district.

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[1] Winslow: loc. cit., Vol. VII, p. 653.

[2] Ibid., p. 666.

[3] Ibid., pp. 650-669.

[4] Ibid., p. 668.

It appears perfectly clear to me that these facts indicate two concentrations. The first was effected by a deep circulation mainly between the shales near the bottom of the Cambro-Silurian limestone and the Devono-Carboniferous shales. At the time of this deep circulation the disseminated ores in the limestones and shales were deposited. The reducing and precipitating agents were clearly the organic matter of the limestones, and especially of the shales. It is notable that the deposits in which there is evidence of a first concentration, with comparatively little effect by a secondary concentration, occur in the district in Missouri in which there has been the deepest mining.

When the Devono-Carboniferous shales were removed by erosion, then began the second concentration by descending waters; and at this time the disseminated ores were taken into solution and concentrated in the crevices, as at places at the Mine La Motte and Bonne Terre areas. At this time the disseminated lead sulphide of the first concentration was oxidized to sulphate. The sulphate was largely carried downward by descending waters, and by reactions between that compound and the marcasite or organic matter reprecipitated as sulphide, thus resulting in a second concentration. At the upper levels, mainly above the level of ground water, lead carbonate (cerussite) was formed by reaction between lead sulphate and calcium carbonate.

The presence of rich deposits of copper pyrites and pyrrhotite carrying workable quantities of nickel and cobalt at Mine La Motte and Bonne Terre at the upper horizons, and their absence at lower horizons, is further evidence of secondary concentration at upper horizons. Indeed, the production of these richer sulphides at higher horizons and their absence or sparseness at lower horizons corresponds precisely to the facts upon which I have based my belief that two concentrations of such copper and nickel deposits have widely occurred, the first by ascending and the second by descending waters.[2]

The two exceptional facts of this subdistrict as compared with other districts are the very great sparseness of zinc ores and the absence of barite.

WASHINGTON AND FRANKLIN COUNTIES SUBDISTRICT AND THE CENTRAL DISTRICT OF MISSOURI.

The subdistrict of Washington and Franklin counties and the Central district of Missouri have the same geological succession as St. Francois and Madison counties; however, the occurrence and character of the ores are very different. The ores of Washington and Franklin counties and those of the Central district and their relations are so similar that they are treated together. The ores occur almost altogether in crevices, pitches, flats, and caves.[1] Winslow's figures of the openings in which the ores occur are practically identical with the figures given by Chamberlin for the lead and zinc districts of Wisconsin.[2] The ores occur lining the walls of the openings or detached from them by solution. Moreover, the mines are mostly shallow, nearly all less than 100 feet deep, being mainly above the level of ground water. In this respect also they are identical with the Wisconsin district at the stage of development when Chamberlin described it. Again, the ores themselves and their vertical order are identical with those of Wisconsin. Moreover, the ores are of the same kind as they are in Wisconsin near the surface; i. e., they are oxidized lead and zinc products and galena. For instance, at the Jumbo shaft dry bone and cerussite were found near the surface.[3] At the Valle mines a very large amount of zinc ore has been mined, mostly as carbonate, but to some small extent as silicate.[4] In some places, as for instance at Lee's diggings, pyrite is found below the galena.[5] Up to the present time the amount of blende is subordinate, but it occurs to some extent associated with the galena. Workings as yet have not gone deep enough to show whether or not considerable blende deposits will be developed below the galena horizon, as in Wisconsin.

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[1] Winslow: loc. cit., Vol. VII, p. 673.

[2] Some principles controlling the deposition of ores, by C. R. Van Hise: Trans. Am. Inst. Min. Eng., Vol. XXX, 1901, pp. 109-113.

In most marked contrast with the mines of St. Francois and Madison counties barite is everywhere abundantly found. Winslow's descriptions mention barite as a prominent gangue mineral in almost every mine, and in a number of places it is so abundant as to become a valuable by-product, as at Belfontaine, Kingston, and the Parole mines.

The lithologic succession of Washington and Franklin counties and the Central district of Missouri; the position of the ore-bearing strata between impervious shales; the correspondence of the inclination of the beds and the drainage and the fact that this inclination is greater than the slopes, so as to cause lower horizons to outcrop at the higher elevations; the manner of the occurrence of the ores, and the nature of the ores themselves—these conditions are all so like those of the Wisconsin district, as described by Chamberlin, that scarcely any other word than identity gives a correct conception of the likeness. If the explanation of two concentrations—one by a deep circulation while impervious strata were above much of the ore-bearing strata, and a second concentration by descending waters after the impervious strata were removed—be correct for Wisconsin, it is sure to apply to the districts of Missouri under discussion.

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[1] Winslow: loc. cit., Vol. VII, pp. 677–722.

[2] The ore deposits of southwestern Wisconsin, by T. C. Chamberlin: Geology of Wisconsin, Vol. IV, 1882, pp. 451–482.

[3] Winslow: loc. cit., Vol. VII, p. 683.

[4] Ibid., p. 687.

[5] Ibid., p. 690.

By comparing these districts with the St. Francois and Madison Counties subdistrict in Missouri, we note additional links in the chain of evidence for two concentrations. The relative sparseness of zinc ores in the St. Francois and Madison Counties subdistrict has been emphasized, and the almost universal absence of barite has been noted. But it has been explained that in Washington and Franklin counties and in the Central district the zinc product is very considerable, and that barite is universally present, and at many of the mines exceedingly abundant. It has been pointed out that the occurrences in St. Francois and Madison counties indicate that the deep disseminated ores are mainly the product of a first concentration by ascending waters. The ores were precipitated where they are by the reducing action of the organic material. Under these circumstances there would be no reason for the formation of barite. It is believed that the relative unimportance of the zinc is at least partly explained by the fact that the first concentration was not sufficient to produce large quantities of these ores. But in the Washington and Franklin Counties and the Central districts a second concentration by descending waters became the controlling factor in the present location and distribution of the ores. Here the late concentration produced zinc carbonate in sufficient abundance to be mined, and also concentrated the lead mainly as galena.

If barium be present as a constituent of the associated rocks, so that barium salts are carried by the underground solutions, the formation of the gangue mineral barite is an incident to the second concentration. When the lead and zinc sulphides of the first concentration, formed below the level of ground water, come above that level as a result of denudation, they are oxidized to sulphates, as already explained. It has also been seen that these compounds react upon the alkaline earth carbonates, producing carbonates of lead and zinc and sulphates of the alkaline earths. Simultaneously the associated cerussite and smithsonite are formed. Supposing the barium to be in the form of carbonate the reactions are as follows:

$$PbSO_4 + BaCO_3 = BaSO_4 + PbCO_3.$$
$$ZnSO_4 + BaCO_3 = BaSO_4 + ZnCO_3.$$

If the barium were in some other form than carbonate the reactions would also involve the carbonates of the other alkaline earths, calcium and magnesium, but the results would be the same so far as the barium is concerned. Ordinarily the chief sulphate of the alkaline earths, formed as an incident to the development of cerussite and smithsonite, is gypsum. But where barium is present the sulphate of this metal is precipitated, because this is so much more insoluble than calcium sulphate. That barium was contained in the solutions in this district is evidenced by the abundant development of barite as a gangue mineral where a second concentration by descending waters has taken place. In this connection it is suggested that an investigation of the character of the limestones of the Southeastern Missouri district may show that barium is a more important constituent there than in the Southwestern Missouri district or in the Upper Mississippi Valley, where barite as a gangue mineral is subordinate.

NORTH ARKANSAS DISTRICT.

While in the field I gave no personal attention to the North Arkansas district, nor did I examine the literature. Mr. Bain, as a result of his field work and of information derived from Branner's report,[1] divides the ores into (1) crevice deposits; (2) breccia deposits, representing zones of crushing in limestone or in limestone conglomerate, and (3) disseminated ores in limestone or limestone conglomerate. All of these deposits are in the Cambro-Silurian limestone. The crevice deposits are similar to those of central Missouri. The breccia deposits, which are now the chief source of ore, have formed along zones of crushing. The disseminated deposits are in the solid limestone or the comparatively unaltered conglomerates. The ores comprise both lead and zinc, the latter being very important. The zinc occurs both as sphalerite and as smithsonite.

Branner strongly insists that the ores are largely concentrated in local synclines and that the anticlines are relatively barren.[2] In this respect the ores have the same relations as those in Wisconsin as determined by Chamberlin.

I do not venture to make any positive statements at the present time as to the manner of concentration of these deposits. However, the work of Branner and Bain seems to me to render it highly probable that in this district, as in the others of the Ozark region, there have been two concentrations: (1) by an artesian circulation between the Fayetteville shale and Boone chert and perhaps below the Devono-Carboniferous shales, and (2) by later concentration by descending waters since the shales were removed by erosion. In these concentrations the synclines may have played the same rôle as in Wisconsin.

With the present state of knowledge no definite opinion can be expressed as to the relative influence of these two circulations; but it may be suggested that the rather large areas of disseminated ores in the compact limestone and unbroken conglomerate largely represent the work of a first concentration, and that the deposits containing oxidized ores associated with sulphides in the crevices and breccias have undergone an important second concentration by descending waters.

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[1] The lead and zinc region of northern Arkansas, by J. C. Branner: Ann. Rept. Geol. Survey of Arkansas for 1892, Vol. V, Little Rock, 1900.

[2] Op. cit., p. 32.

GENERAL.

Considering now the Mississippi Valley lead and zinc region as a whole, disregarding the names of formations, and considering only the lithologic succession in each district, we have in descending order: (1) Thick shale formation, (2) limestone-bearing ore bodies, (3) shale, (4) limestone-bearing ore bodies, (5) shale, often interstratified with limestone, (6) sandstone, (7) pre-Cambrian. In some of these districts a portion of these formations has been removed by erosion. In Wisconsin the great majority of the important ore bodies occur in the upper limestone, and this limestone was once bounded upon both sides by shale. In the Missouri districts important ore bodies occur in both limestones; and both of these limestones are bounded by shales at many localities. The productive upper limestone formation in Missouri, restricted to the Southwestern district, probably derived its ores from the lower limestone formation, whereas in Wisconsin the main ore bodies were probably derived from the limestones in which they occur, and this is true in Missouri of the Southeastern and Central districts.

Wherever the full vertical distribution of ores is known it is essentially the same in each of the districts. Above and near the level of ground water oxidized zinc and lead ores with galena occur; below the level of ground water are zinc sulphides with subordinate quantities of lead sulphide; and at depth iron sulphides increase and locally become dominant. In these statements the ores which occur in the crystalline rocks of Missouri are not considered, and to them these statements as to the vertical distribution are not applicable.

In all of the districts the Cambro-Silurian limestone is regarded as the immediate source of the ores. Through these limestones are widely dispersed, minute quantities of lead and zinc compounds which served as the supply. Nothing has been said as to how the lead and zinc compounds became distributed in the Cambro-Silurian limestone. Upon this point no important suggestion has been added by the present investigation. As is well known, Chamberlin has propounded an elaborate theory for the original precipitation of the lead and zinc ores from sea water in Cambro-Silurian times by the reducing action of seaweeds segregated in Sargasso seas or eddies.[1] According to Chamberlin, Mr. Buell has calculated that if the source of the metal in the Potosi area, one of the richest in the Wisconsin district, be restricted to a layer 100 feet deep and limited on the outside of the area of paying crevices by half the average distance between the crevices, to account for all the lead which had been taken out it would only be necessary to suppose that the rock contained "one fourteenhundredth of 1 per cent, or a little more than one seven-millionth of the rock."[1]

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[1] Ore deposits of southwestern Wisconsin, by T. C. Chamberlin: Geology of Wisconsin, Vol. IV, 1882, pp. 529–544.

While the widespread occurrence of lead and zinc in the Cambro-Silurian limestone of the Mississippi Valley bounded by relatively impervious shales leaves no doubt in my mind that the limestone itself is the main source of the ores, I express no opinion as to the manner in which the exceedingly small fraction of 1 per cent of the lead and zinc was originally deposited in the limestone.

If the theory above given be correct the occurrences of the lead and zinc in all of the districts of the Mississippi Valley furnish excellent illustrations of that class of ores produced as a result of a first concentration by ascending waters and a second concentration by descending waters. Moreover, all of these districts illustrate with remarkable clearness the very important influence of impervious strata in the development of ore deposits, a principle which, so far as I know, was first emphasized in my papers on the Lake Superior iron ores and which was fully developed in my paper on the deposition of ores.[2] Finally, these deposits illustrate beautifully the facts that comparatively shallow circulations may at the point of precipitation first deposit ores by ascending waters, and that these ores may have been concentrated by descending waters.

The similarity as to lithologic succession, occurrence of the ores, and genetic relations between the ore deposits and the stratigraphy in these widely separated districts in the Mississippi Valley seems nothing short of marvelous. Identity seems the only word which fits the case for several of the districts. Whether the above explanation of this similarity be correct or not, I have absolutely no doubt that the same general explanation is applicable to all of the districts. The phenomena of one district can not be explained in independence of the others or in a different manner. If the explanation given be correct in reference to the Southwestern district of Missouri—and from it there seems no escape—it is also applicable with minor modifications to the other lead and zinc districts of the Mississippi Valley.

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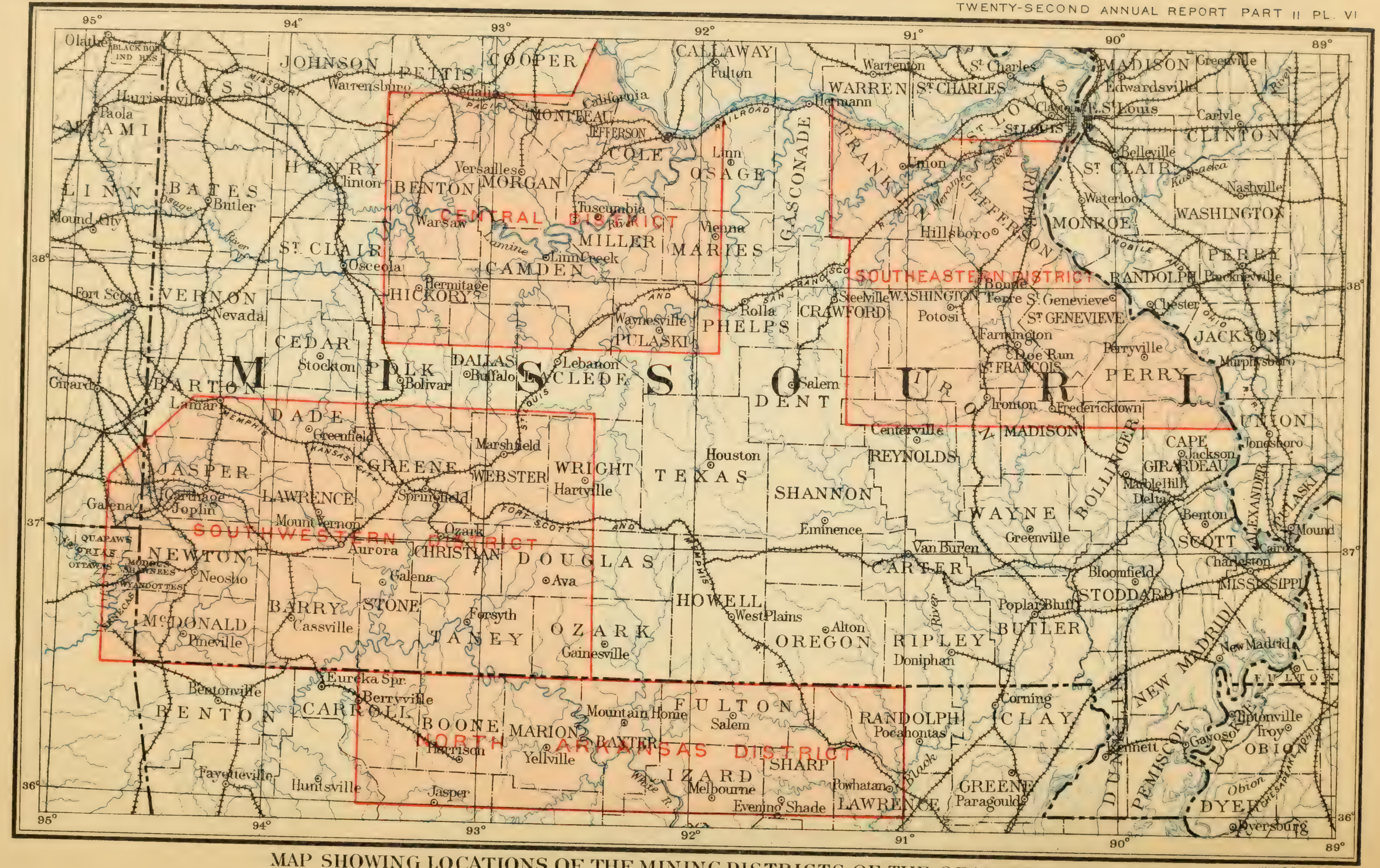
[1] Chamberlin: loc. cit., p. 538.

[2] Some principles controlling the deposition of ores, by C. R. Van Hise: Trans. Am. Inst. Min. Eng., Vol. XXX, 1901, pp. 27-177.



MAP SHOWING LOCATIONS OF THE MINING DISTRICTS OF THE OZARK REGION

Scale

40 0 40 80 MILES

JULIUS BIEN & CO. N.Y.

CHAPTER I.

By H. F. Bain.

GENERAL STATEMENT.

DEFINITION OF REGION AND COMMERCIAL IMPORTANCE.

The Ozark region is roughly an elliptical area, approximately 300 miles in length from northeast to southwest and 200 miles in breadth. It embraces the southern half of Missouri, the northern third of Arkansas, and small adjacent portions of Illinois, Kansas, and Indian Territory. While it differs in general appearance and in many structural features from most mining regions, it is rich in minerals of economic importance and includes a number of important mining districts. The great iron deposits of Pilot Knob and Iron Mountain, the manganese beds of Batesville, the smaller amounts of copper, nickel, and cobalt at Mine La Motte, the silver and associated minerals of the Einstein mine, with the zinc and lead deposits which it is the specific purpose of this paper to describe, all attest the mineral richness of the region. One of the zinc districts, the Joplin or Missouri-Kansas district, now produces approximately 90 per cent of the zinc ore mined in the United States, or 20 per cent of the world's production. The lead region of southeastern Missouri also produces approximately 22 per cent of the United States output of lead and 7 per cent of that of the world.

SUBDIVISIONS OF REGION.

Commercially the zinc and lead fields of the Ozarks fall into four subdistricts. These are shown in Pl. VI, and are enumerated below.

1. The Southeastern Missouri district, essentially lead producing, and best known through its disseminated ores and the large mining and milling operations which that form of deposit has made possible.
2. The Southwestern Missouri or Missouri-Kansas district, of which Joplin is the best-known city. This is essentially a zinc-producing district, though an important amount of lead ore is also mined. It is characterized by great irregular runs of rich ore, which will be more particularly described later.
3. The Central Missouri district, a region of indefinite outline not

yet fully prospected, and characterized, so far as yet developed, by smaller ore bodies of both lead and zinc.

4. The North Arkansas zinc region, an extensive area as yet only partially prospected and almost wholly undeveloped, but showing a wide variety of rich ores and some very promising prospects.

Geographically the boundaries of these districts are not distinct, since small quantities of zinc and lead have been found throughout the Ozark region. Commercially the districts are fairly well differentiated, and the stage of development and methods of work in each are distinctive.

Geologically the deposits of the region fall into two, rather than four, classes. These classes are: (*a*) deposits in the Carboniferous limestones and cherts; (*b*) deposits in the Cambro-Silurian dolomites and magnesian limestones. The principles upon which the geological classification is based are far better defined than those upon which the mines are grouped into commercial and geographical districts. They include points of association, genesis, and common form of ore body. The geological classification has economic importance in its bearing on the extent and probable duration with depth of the deposits.

In the present report the deposits in the Carboniferous are particularly discussed. The Cambro-Silurian ore bodies have been investigated only with reference to their bearing on various questions arising in the course of the work on the deposits in the Carboniferous, and at such times in the course of the latter work as were possible. A comprehensive view of either class of ore bodies in this region necessitates a fair knowledge at least of the other, and any final study of permanent value must be based upon a complete investigation of both throughout the Ozark region. In addition to the ore bodies of the Ozark region, those of the Ouachita Mountains, in southwestern Arkansas, were visited. No complete study was made of these mines, but a few notes on them are included in this report.

HISTORICAL RÉSUMÉ OF DEVELOPMENT.

While mining in Missouri dates back to the earliest period of settlement and even of exploration, and lead mining in particular has been carried on since early in the eighteenth century, activity in zinc mining is comparatively recent. There is a popular belief that the failure to develop the zinc ores earlier was due to the lack of recognition of the presence of zinc. Blende was, however, very early determined to be present, though it is doubtless true that the early miners in general had no real conception of its value.

The lead mines were earlier developed because the first attempts at mining were made in southeastern rather than southwestern Missouri, and in the southeast blende is relatively rare while galena is abundant.

The greater ease with which galena may be reduced and also the need among the pioneers for bullets were doubtless most important factors in confining mining to the galena. The common mode of occurrence—galena at the surface and mingled with the soft residual clays, with blende at greater depths and in harder rocks—was not without its influence. Probably, however, difficulty in smelting was the chief factor in preventing earlier development of the zinc fields. For many years only the oxidized zinc ores could be economically smelted. It was not until the Mattheison and Hegler works at La Salle, Ill., developed the process of smelting blende that the sulphide came to have value. This was the first plant in the world to economically smelt blende on a commercial scale.

Zinc was not recognized as an independent metal until the thirteenth century, and it was not until the middle of the eighteenth that works for its reduction were established in Europe. In America zinc was first manufactured in the Washington arsenal in 1838,[1] and in the West the first attempt to smelt zinc ores was made by Messrs. Mattheison and Hegler at La Salle, Ill., in 1852. The presence of zinc ores in the Mississippi Valley was mentioned as early as 1810,[2] and Schoolcraft,[3] in 1819, mentions zinc as having already been exported from Missouri Territory. Succeeding geologists who visited the mines of the Mississippi Valley noted the presence of zinc, and Percy, the first State geologist of Wisconsin, shipped a small quantity to New Jersey for reduction in order to demonstrate its value. It was not, however, until 1867 that a zinc furnace was established in Missouri.[4] The development of the zinc fields has distinctly followed and resulted from mining of lead.

Lead mining began in southeastern Missouri in 1719, but did not develop much until 1800. From that year to 1820, and again from 1830 to 1850, mining was active throughout the region. In 1851 mining began in the Southwestern district near the present site of Oronogo, though ore had been discovered much earlier. The civil war interfered very materially with mining, but at its close the mines were reopened and the industry had expanded considerably. Noteworthy incidents were the introduction of the diamond drill in the Southeastern district in 1869[5] and the resulting discovery of great bodies of disseminated ore, which have since yielded so heavily; and the placing of zinc ores in the market from the southeast in 1867,[6] and from the southwest in 1871.[7] Since that period the development of both districts has been steady, though the years 1898 and 1899 have seen exceptional development, especially in the Southwestern district, where, for the first time, large investments have been made by outside capital.

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[1] R. W. Raymond: American Cyclopedia, Vol. VI, p. 816.

[2] Arthur Winslow: Missouri Geol. Survey, Vol. VI, p. 13, citing H. M. Brackenridge, jr., Views of Louisiana, etc., Pittsburg, 1814, p. 304.

[3] H. R. Schoolcraft, View of the Lead Mines of Missouri, etc., New York, 1819, p. 44.

[4] Winslow: loc. cit., p. 14.

[5] J. Wyman Jones: Eng. Mag., Vol. XIII, 1897, pp. 358-366.

[6] Chas. P. Williams: Industrial Report on Lead, Zinc, and Iron [Mo.], Jefferson City, 1877.

[7] Winslow: loc. cit., p. 294.

TABLES OF PRODUCTION.

The general development of the region and the periods of activity are indicated by the following statistical tables.

The best figures available up to 1893 are those of Winslow, and Table I was compiled by him. The figures cover the production of the Missouri mines only, and particularly for the later years should be increased by a considerable amount to show the totals for the region.

TABLE I.—*Total production of lead and zinc in Missouri by periods.* (*a*)

Year.	Lead.			
	Ore.		Metal.	
	Tons.	Value.	Tons.	Value.
1720–1799	36,000	$1,440,000	18,000	$1,800,000
1800–1819	42,200	1,689,000	25,300	2,280,000
1820–1829	30,800	1,231,000	19,100	1,908,000
1830–1849	112,900	4,516,000	73,400	6,604,000
1850–1859	73,100	2,923,000	51,100	5,526,000
1860–1869	45,100	2,706,000	31,600	5,370,000
1870–1879	229,500	11,476,000	160,700	18,961,000
1880–1893	530,200	22,756,000	371,100	31,432,000
Total	1,099,800	48,737,000	750,300	73,881,000

Year.	Zinc.			
	Ore.		Metal.	
	Tons.	Value.	Tons.	Value.
1860–1869	200	$2,000	100	$8,000
1870–1879	156,400	1,680,000	56,000	6,524,000
1880–1893	1,058,700	20,932,000	433,000	43,291,000
Total	1,215,300	22,614,000	489,100	49,823,000

[a] Missouri Geol. Surv., Vol. VII, p. 540.

In the years later than 1893 the statistics of the Southwestern district as a whole have been collected with great care by Mr. Frank Eberle, of Joplin. The totals are given below in Table II and the detailed production by camps for 1900 in Table III.

TABLE II.—*Production and value of lead and zinc ores in the Southwestern district.*

Year.	Zinc ore.		Lead ore.		Total value.
	Tons.	*Value.*	*Tons.*	*Value.*	
1894	137,547	$3,014,551	22,362	$670,830	$3,685,381
1895	139,023	2,919,483	28,337	708,425	3,627,908
1896	157,083	3,200,885	26,740	666,510	3,867,395
1897	169,476	3,908,367	30,875	925,270	4,833,637
1898	234,432	5,966,241	26,791	1,205,573	7,171.814
1899	257,677	9,539,009	24,259	1,263,468	10,802,477
1900	244,246	7,968,239	29,177	1,382,778	7,968,239

TABLE III.—*Production of the Southwestern district, by camps, in 1900.*

Camp.	Zinc.		Lead.	
	Pounds.	*Value.*	*Pounds.*	*Value.*
Joplin, Mo	109,752,710	$1,537,374	22,978,889	$537,643
Galena, Kans	90,085,650	1,202,054	10,118,670	245,905
Carterville, Mo	78,292,520	1,052,143	14,529,370	351,681
Aurora, Mo	44,393,230	545,820	1,409,660	31,321
Oronogo, Mo	36,279,590	511,853	317,110	7,291
Webb City, Mo	25,286,680	344,480	2,303,210	55,646
Zincite, Mo	18,772,670	283,751	379,770	8,810
Granby, Mo	15,675,640	182,213	997,790	22,560
Duenweg, Mo	10,294,490	124,268	1,646,240	36,268
Neck City, Mo	8,172,170	120,443	38,550	936
Central City	7,910,920	103,981	458,530	11,241
Stolts City	7,431,130	110,587	181,587	4,322
Cave Springs	7,764,640	103,530	467,310	9,994
Roaring Springs	7,155,320	90,890	699,290	17,586
Carthage	6,573,490	85,775	46,730	1,012
Carl Junction	5,765,470	79,805	5,140	143
Alba	1,834,300	24,963	....	....
Springfield	1,080,440	17,144	98,080	2,256
Spring City	1,238,150	13,888	583,860	13,353
Spurgeon	1,425,350	15,283	639,100	14,195
Ash Grove	297,590	2,576	376,100	8,964
Everton	1,139,410	9,118	....	....
Seneca	610,830	4,248	79,230	1,651
Wentworth	986,950	15,033	....	....
Mosley	127,700	894	....	....
Ozark	145,540	3,347	....	....
Total	488,492,580	6,585,461	58,354,216	1,382,778

The recent production of lead and zinc for the entire region is shown in Table IV. In this table is given the production of spelter by the smelters of Kansas, Missouri, Illinois, and Indiana, and the smelters' returns of lead from ores of the Mississippi Valley. The spelter production is essentially that of the Ozark region. The amount of ore derived from the Upper Mississippi mines and going into the manufacture of spelter is not important and probably is counterbalanced by the amount of silicate ore from the Southwestern district which is used in the manufacture of zinc oxide. The pig-lead production is high by the amount derived from the Upper Mississippi mines and low by the amount used at Joplin in the manufacture of white lead. The total amount of lead produced in the Ozark region is very probably greater than is shown by the table. The prices given are ruling New York prices. In comparing the table with Table I, it should be remembered that the value of lead in the latter is based on St. Louis prices, which are normally lower than those of New York.

TABLE IV.—*Production of zinc and lead from ores of the Ozark region.*

Year.	Lead.		Spelter.	
	Production. *a*	Price per lb. *b*	Production. *a*	Price per lb. *b*
	Short tons.	*Cents.*	*Short tons.*	*Cents.*
1894	46, 300	....	66, 552	3. 63
1895	53, 596	3. 23	76, 505	3. 63
1896	51, 887	2. 98	70, 833	3. 94
1897	56, 542	3. 58	89, 397	4. 12
1898	54, 469	3. 78	106, 768	4. 57
1899	....	4. 47	*b* 120, 872	4. 75

a Kirchoff, Chas.: Twentieth Ann. Rept. U. S. Geol. Survey, Pt. VI, pp. 226, 250.
b Rothwell, R. P.: Mineral Industry, 1900.

PREVIOUS GEOLOGICAL WORK.

The ore deposits of the region have been studied by many geologists and mining engineers. The early geologists of the region recognized their importance and devoted much attention to their study. It will not be necessary to summarize their results, since Mr. Arthur Winslow, late State geologist of Missouri, has already excellently done so.[1] Attention should, however, be directed to the report of Adolf Schmidt on the mines of the Southwestern and Central districts[2] as being particularly full of details. Indeed, the facts concerning the entire region are pretty well known, and with regard to most of them there is little controversy. The interpretation of these facts has varied widely.

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[1] Missouri Geol. Survey, Vols. VI and VII, 1894.

[2] Missouri Geol. Survey, Vol. I (Broadhead), 1873–1874, pp. 381–577.

Winslow's own contribution to the knowledge of the region is by far the most important yet made, and in the two volumes cited is found the most general discussion now available. He covers in considerable detail all the Missouri districts and gives some notes on those of northern Arkansas. The report is at the same time a valuable book of reference on the general subjects of lead and zinc. A special paper on the Southeastern district[1] adds much of importance, and still further details are given in papers published in the Transactions of the American Institute of Mining Engineers and elsewhere. Aside from Winslow's papers, the most significant and valuable article on the ore bodies recently published is that by Prof. W. P. Jenney.[2] These papers and the discussion which they provoked have helped greatly to a right understanding of the ores. The interpretations of the region given by Jenney and by Winslow were sharply antagonistic. Jenney emphasized the importance of ascending waters while Winslow insisted on the greater importance of descending waters, acting mainly through residual concentration in producing the ore bodies. The present studies have led to the belief that both were to a considerable degree correct, but that each overemphasized certain phases of the processes concerned.

SCOPE OF PRESENT REPORT.

The present report must be considered as essentially preliminary. It deals with principles and their application to the region rather than with details of structure and areal distribution. It is regretted that the time which could be devoted to the work was so limited as to preclude any complete mapping. The descriptive portion is accordingly not complete. The camps and mines described are chosen with reference to the illustration of the principles concerned rather than because they are particularly rich or poor or even because they represent average conditions in that particular. In nearly every instance some other mine could have been chosen which would serve equally well as an illustration. The choice was determined largely by circumstances and convenience.

ACKNOWLEDGMENTS.

The field work upon which this report is based was carried on principally between July and November, inclusive, in 1900. The writer had the very great benefit of field conference with Mr. S. F. Emmons, Mr. Bailey Willis, and Prof. C. R. Van Hise, and of constant consultation with the last two named during the preparation of the report. To them he is indebted for very many fruitful suggestions and helpful criticisms. To Professor Van Hise the debt is particularly heavy, as the work was carried out under his immediate supervision and is essentially an application to this particular region of the general principles controlling the deposition of ores which he has recently formulated. The material contained in his notable paper has been very freely drawn upon.

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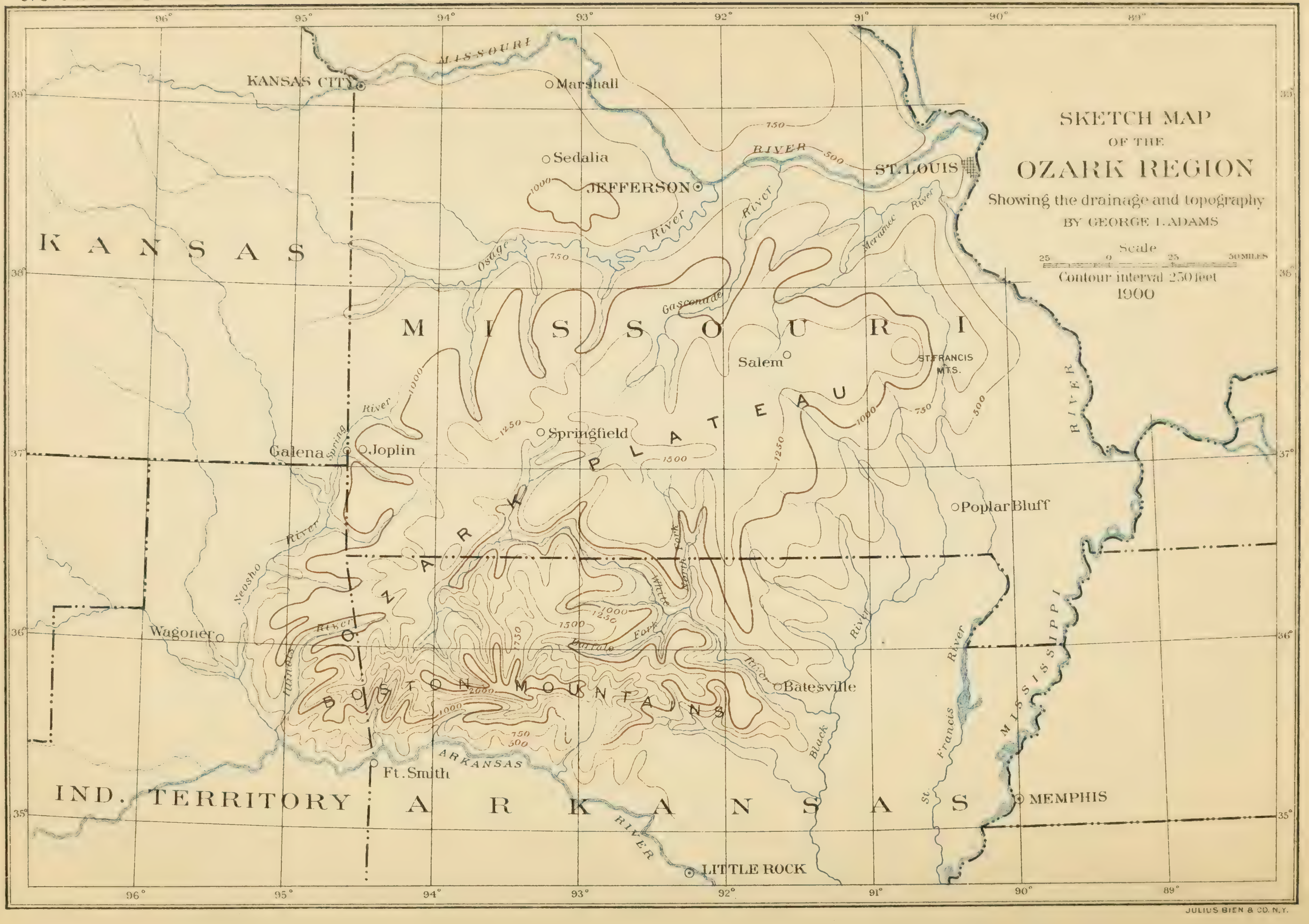
[1] Bull. U. S. Geol. Survey No. 132.

[2] Trans. Am. Inst. Min. Eng., Vol. XXII, p. 171.

In the field assistance was given by Messrs. George I. Adams and E. F. Burchard in geologic work and Messrs. W. H. Griffin and Basil Duke in the course of their work on the topographic sheets accompanying the report. Mr. Adams has also been of material assistance in the office, particularly in the compilation of maps, sections, and illustrations. Mr. C. K. Leith has kindly read and criticised the entire report, and examined the thin sections studied microscopically.

Throughout all published material was freely drawn upon and general acknowledgments are due to previous workers in the field. Particular acknowledgments are due to Prof. E. M. Shepard, of Drury College, who placed at the writer's disposal many important and unpublished notes and spent several days in the field with him. The mining men and landowners generally throughout the region did everything possible to facilitate the work. Special acknowledgments are due to W. S. Hutchinson, C. T. Mixer, W. B. Fisher, R. P. Bowyer, C. C. and George Playter, Ed. Johnston, J. R. Milner, George F. Dent, Capt. C. B. Dahlgren, A. L. Hotom, and F. Thomas Ransome. It is regretted that limitations of space forbid the mention by name of many others who contributed their time and experience.



SKETCH MAP
OF THE
OZARK REGION
Showing the drainage and topography
BY GEORGE I. ADAMS

Scale
25 0 25 50 MILES

Contour interval 250 feet
1900

JULIUS BIEN & CO. N.Y.

CHAPTER II.

By George I. Adams.

PHYSIOGRAPHY.

GENERAL FEATURES.

Broadly defined, the Ozark region[1] embraces the southern half of the State of Missouri, a very small corner of southeastern Kansas, the northeastern part of Indian Territory, and the northern part of Arkansas. On its borders are the cities of St. Louis, Jefferson, Marshall, Sedalia, and Joplin in Missouri; Galena in Kansas; Wagoner in Indian Territory; Fort Smith and Batesville in Arkansas, and Poplar Bluff in Missouri. In a general way the Mississippi and Missouri rivers bound it on the northeast and north; Spring, Grand, and Arkansas rivers approximately limit it on the west and south, while the upper portions of the St. Francis and Black rivers mark its southeastern margin. The Ozark lead and zinc fields are situated within this area.

Throughout most of its extent it is a simple rolling plain, and in the more rugged parts the broken character is evidently the result of erosion by streams which have deeply dissected a generally even surface. The simple structure, the prevalence of unaltered sedimentary rocks, the entire absence of volcanic agencies, and the limited occurrence of crystalline rocks place the country in contrast with mining regions in general. As compared with the Mississippi Valley the region is an elevated one. To the north and west of it lie the Prairie Plains; to the east and southeast are the Gulf Plains. East of the Mississippi River and separated by the valley of that stream from the Ozark Plateau are the Shawnee Hills, which extend across southern Illinois from the south of the Big Muddy to Shawneetown on the Ohio River. These hills are a structural continuation of the Ozark Plateau. To the south of the Ozark region, but with a different type of structure, is the Arkansas Valley region, and beyond it the Ouachita Mountain region.

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[1] The term Ozark has been variously applied. It was first used by G. C. Broadhead, and the reader is referred to a chapter by him in Volume XII, Missouri Geological Survey. The Ozark region is here discussed in a somewhat different manner, inasmuch as it is considered as related to the Arkansas Valley and Ouachita Mountain regions. Cf. Characteristics of the Ozark Mountains, by C. R. Keyes: Missouri Geol. Survey, Vol. VIII, 1895, pp. 317-352.

Considered in its broader relations, the geological history of the Ozark region is complex. At the close of the Paleozoic era a thick mass of sediments which had accumulated over southern Missouri, Arkansas, and parts of Indian Territory and Kansas was lifted above the level of the sea, producing an elevated region which in its southern part has a folded structure.

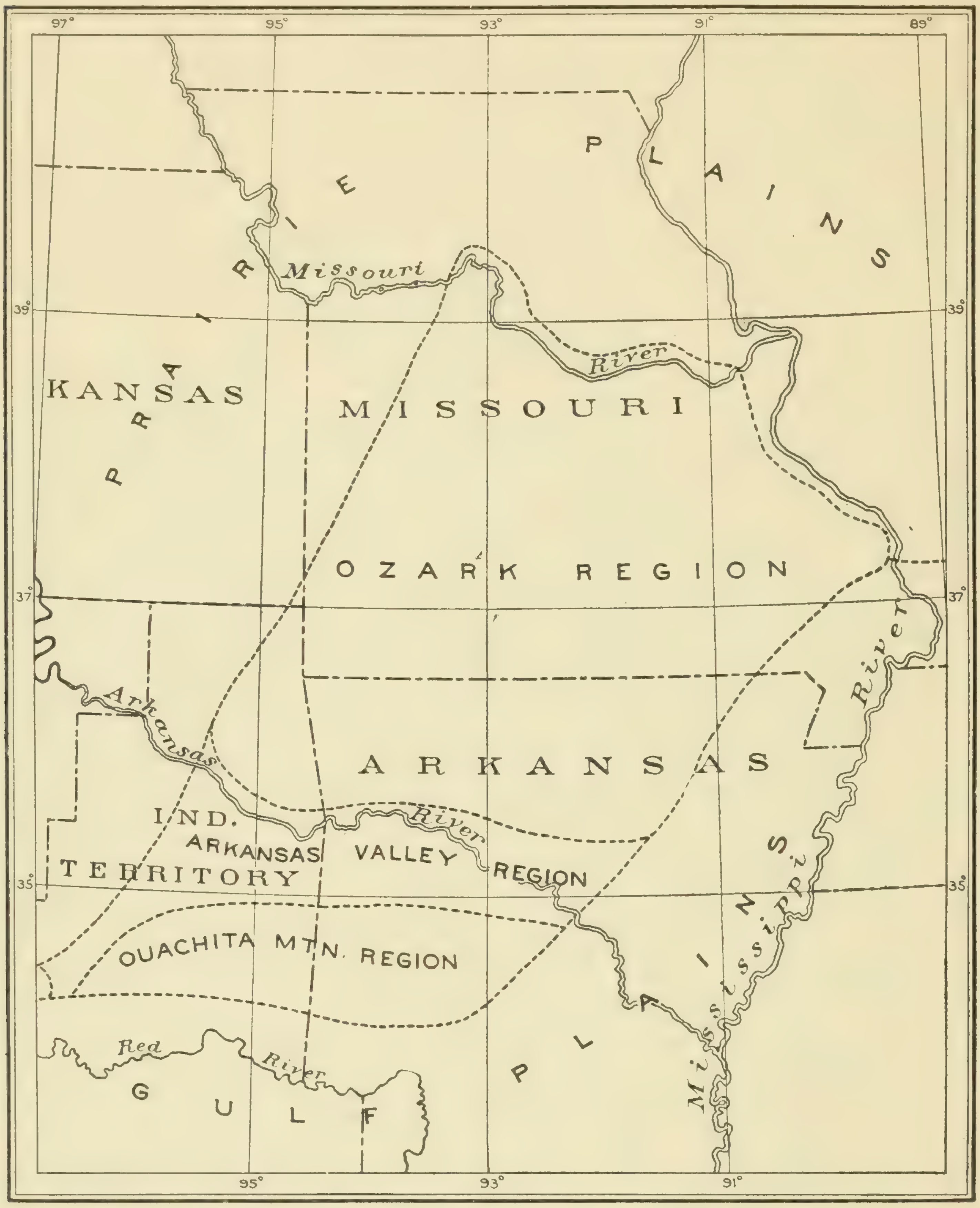

FIG. 3.—Sketch map showing the physiographic relations of the Ozark region.

The force which caused the folding was compressive; the elevation may have been a coincident or later effect. In central Arkansas and eastern Indian Territory the folding produced the Ouachita Mountain structure,[1] which is characterized by close folding and faulting. To the

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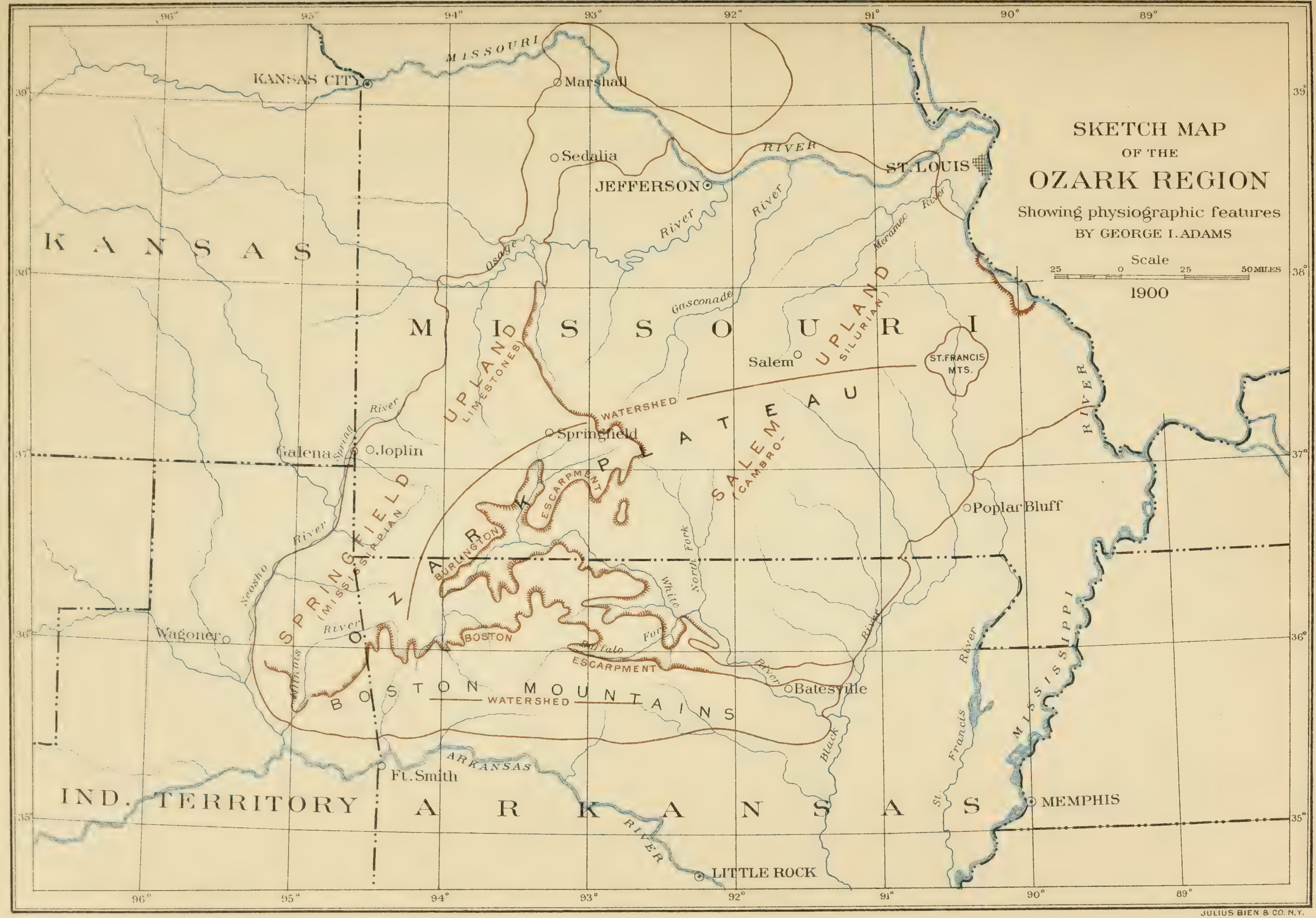
[1] Structural features of the Ouachita Mountain Range in Indian Territory, by Joseph A. Taff: Science, Feb. 2, 1900, pp. 187-188.



SKETCH MAP
OF THE
OZARK REGION
Showing physiographic features
BY GEORGE I. ADAMS

1900

JULIUS BIEN & CO. N.Y.

north of this it produced the wide and open folds which are exhibited in the Arkansas Valley.[1] Farther north is the Ozark region, in which the forces developed a more simple structure. The Boston Mountains, on its southern border, are of a monoclinal type, while the plateau portion, or northern part, has the form of a low dome, with local faulting and minor undulations. The structure produced during this mountain-making period gradually dies out to the west and north, where the formations are inclined at low angles, dipping away from the Ozark Plateau, and the topography is characterized by step or escarpment features, such as are usually found in nearly horizontal rocks. To this region, which extends around the northern and northwestern border of the Ozark Plateau, the name Prairie Plains has been given.[2] In Cretaceous time there was a subsidence in the Gulf region and sediments were deposited which conceal the southern border of the Ouachita Mountains. A later oscillation occurred which caused the eastern extension of that mountain range to be buried under sediments of Tertiary age. This region, which is covered by Cretaceous and Tertiary sediments, is in general low lying and is known as the Gulf Plains.[3] Just how these oscillations affected the Ozark region is not readily determined. There were undoubtedly warpings of the strata as the sea in the Gulf region retreated, advanced, and again retreated, but the structure which was developed at these intervals has not yet been differentiated from the previous faulting and folding. The generally even sky-line of the plateau portion indicates a time during which the area was worn down to a lowland. This was probably the condition in late Tertiary time. Since then the region has been elevated and the streams have carved deep valleys. The remnants of the old lowlands now constitute uplands and along the streams narrow lowlands are being developed.

OZARK PLATEAU AND BOSTON MOUNTAINS.

The Ozark region may be considered as consisting of two divisions—the Ozark Plateau and the Boston Mountains. The Boston Mountains occupy the southern portion of the region. Their northern border forms an irregular escarpment overlooking the plateau above which they rise from 500 to 700 feet. They have in general a monoclinal structure. The dip of the rocks is to the southward, and the southern slope of the mountains blends with the Arkansas Valley region. Their trend is approximately east and west from Batesville, Ark., to within a few miles of Wagoner, in Indian Territory. The formations which constitute the mountains are sandstones and shales, and as a result the topography is largely of the terrace and escarpment type. The area is very broken as a result of dissection by the streams.

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[1] Physiography of the Arkansas Valley region, by George I. Adams: Science, March 30, 1900, p. 508.

[2] Physiographic regions of the United States, by J. W. Powell: Nat. Geog. Monograph, 1895, p. 83.

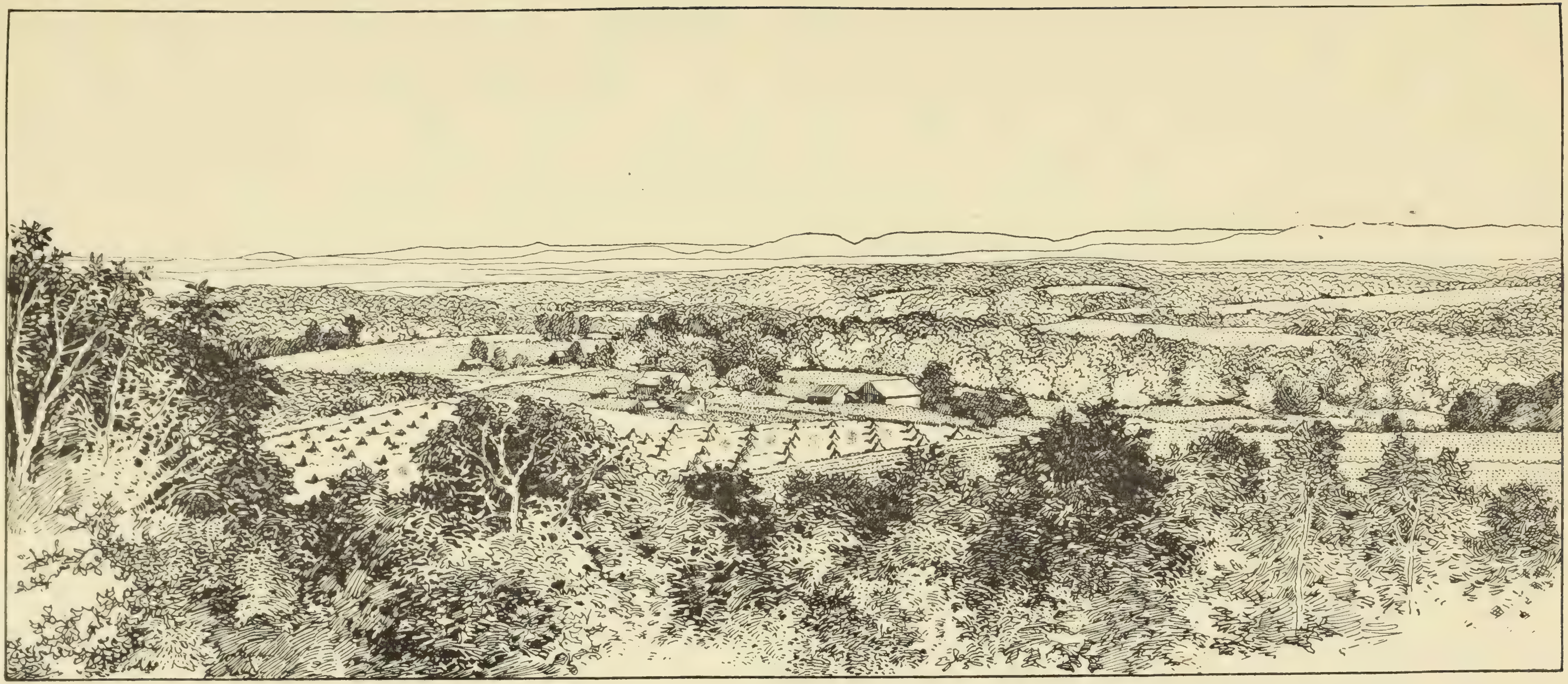
[3] Powell: loc. cit., p. 84.

The Ozark Plateau portion is deeply dissected in its central and eastern parts, and in places the topography is rugged, but locally the elevations rise to approximately the same general horizon, so that, viewed in its entirety, it has the shape of a low elliptical dome, ranging in elevation between 1,000 and 1,500 feet above sea level.

In the southeastern part of Missouri, in the vicinity of Pilot Knob and Iron Mountain, the surface features of the plateau are of an exceptional character. Within an area approximately 70 miles square, known as the Iron Mountain country, there is a group of peaks, to which the name St. Francis Mountains has been applied. The rocks which form them are crystalline, and erosion has developed a type of topography different from that which prevails generally over the plateau. The mountains rise from 500 to 800 feet above the surrounding valley and from 1,200 to 1,800 feet above sea level. They do not constitute a regular system, but instead are irregular ridges, knobs, and conical peaks separated by valleys which wind in among them. Pilot Knob is approximately the center of this district, and Iron Mountain is perhaps the best known of the peaks. Between the crystalline masses which form the mountains there are areas of stratified rock which are gradually being eroded. Their relations appear to indicate that the present mountain masses represent an old topography which is being exhumed. The present slopes are peculiarly rounded and gentle and attest the long continued action of eroding agencies.

The drainage of the Ozark Plateau is believed to be consequent, the arrangement of the streams being radial—that is, down the slopes of the dome. While this is true of the higher portions of the region, yet along its borders there are seeming departures from this arrangement. One of the most conspicuous examples of what might appear to be a modified phase of drainage is given by White River. It is formed by a number of streams which rise along the northern slope of the Boston Mountains, and is joined by others which flow southward from the higher parts of the Ozark Plateau in Missouri. It flows northward, then northeastward, and finally southeastward, its course evidently having been determined by the Boston escarpment, which in former periods occupied a position farther north. Since the establishment of this stream, erosion has removed a great thickness of the rocks which were the equivalents of those in the northern slope of the Boston Mountains, and the river now lies within a narrow gorge in the lower rocks.

The valleys of the streams exhibit two phases of development, both of which are represented along many of the larger streams and which grade into each other without sharp distinction. The older and simpler phase is an open trough bordered by hills and without rocky ledges adjacent to the stream. This condition is usually exhibited in the upper portions of the streams. The valley is generally covered with



VIEW OF BURLINGTON ESCARPMENT, LOOKING SOUTH INTO ARKANSAS FROM NEAR ROARING RIVER, BARRY COUNTY, MO.

residual cherts and the stream bed is floored with them. The channel is not occupied by water, except during the time of protracted rain, and it is not bordered by bottom lands. The other phase, found in the lower portion of the streams, is the canyon phase, and where this prevails there are many tributary springs and there is usually sufficient water to render the streams perennial. In this part of their course some of the streams have developed flood plains, and furnish rich, although usually narrow, bottom lands. The best example of this condition is found in White River, which lies from 250 to 500 feet below the general surface of the upland. Tributary to the canyons are numerous short-stream valleys, which owe their depth to the grade of the larger stream. They are formed by sapping back from the main channel, and have very little headwater drainage. Along the main valleys numerous smaller streams have dissected the plateau, and the country is broken by narrow points extending out from the general area of the upland surface. These form a complicated series of hills and ridges over which the soil is shallow.

On the general surface of the plateau, where broad undissected areas exist, there is a peculiar form of drainage that is without definite channels. It exists in areas known as flat woods land, and also in untimbered areas where the water largely disappears under residual cherts and in underground channels.

SALEM UPLAND AND SPRINGFIELD UPLAND.

The Ozark Plateau is divided into the Salem upland and the Springfield upland by the Burlington escarpment, which crosses it in a general north-south direction.[1] This escarpment is the border of the Mississippian limestones, which constitute the country rock of the western part of the plateau. The escarpment limits the Cambro-Silurian area to the westward, and in crossing it there is a noticeable rise, although the increased elevation is not maintained, since the dip of the rocks is away from it. That the Mississippian limestones have been eroded from over a large part of the Salem upland is evidenced by the small residual areas of those rocks and the accumulation of cherts derived from them by weathering and erosion. The escarpment, where well defined, has an altitude of from 250 to 300 feet. To the east of Springfield, near Cedar Gap, it stands out at a greater elevation than in any other part of the region, inasmuch as at this point it is farthest up on the divide of the Ozark Plateau. In Arkansas, White River and its tributaries have cut a wide embayment into it. It extends in its southern portion in an approximately east-west line parallel with the northern escarpment of the Boston Mountains.

The eastern portion of the Ozark Plateau is the Salem upland. Its surface is that of a general plain interrupted by the valleys which have been cut into it and by occasional hills rising above it. The streams flow in steep-sided narrow valleys, some of which reach a depth of 250 feet or more. Where the country is not dissected it is an undulating upland, but along the lower portion of White River and its tributaries, and along some of the other large streams, dissection has gone so far that the plain is scarcely recognizable, except as indicated by the general elevation of the higher points. The hills which rise above the plateau are of two kinds—those which protrude through the strata forming the upland surface, and those which are remnants of higher formations. Of the former type are the hills and peaks of crystalline rock which are found in the southeastern part of Missouri and form the St. Francis Mountains. The second group consists of residual areas of rocks which originally overlaid the surface, but which have been largely carried away by erosion. They are outliers from the main area of Mississippian limestones farther west.

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[1] Physical features of Missouri, by C. F. Marbut: Missouri Geol. Survey, Vol. X., 1896, pp. 11-110.

The Springfield upland is essentially a structural plain developed on the surface of the Mississippian limestones. The drainage of the upland in its broader part, namely, in southwestern Missouri and Indian Territory, is in general in the same direction as the dip of the rocks, westward and southwestward. The larger streams begin near the eastern border of the area and have their upper courses in shallow troughlike valleys; they cut deeper as they flow farther down the slope, and in places expose the underlying Ordovician rocks, which rise in anticlines and low domes. Adjacent to Grand River the border of this area is very much dissected by numberless short streams whose valleys are deep in proportion to their length. The streams that flow eastward and pass over the Burlington escarpment have but a small portion of their course on the Springfield upland. They have deep channels, due to the fact that they pass over the edge of the Mississippian limestones, into which they have cut a ragged fringe.

The Springfield upland extends into Indian Territory westward to Spring River and Grand River. Along the Illinois River it forms an embayment in the Upper Carboniferous area, which has the peculiarity of extending down the stream as a result of the dip of the rocks. In southeastern Kansas and in the western part of Missouri it grades off into a lowland country, approximately along the contact of the Upper Carboniferous formation.

The Illinois River of Arkansas, which rises on the northern base of the Boston Mountains, flows northward, then westward, then southwestward. In its northward course it flows away from the Boston Mountains into the border of the Springfield upland, while in its southwestward course it cuts through the Boston escarpment. It flows in a deep, well-defined valley, and, judging from its course with respect to the Boston escarpment and its relation to outlying areas and headlands of the Boston group, it has evidently descended from a much higher plain.

The northern part of the Springfield upland is crossed by the Osage River, which has a very tortuous course, probably due to meanders which were developed before it eroded its channel into the Mississippian limestones. The western border of the Springfield upland is indefinite, especially where it is coincident with the outcrop of the soft Coal Measures shales and sandstones which form a lowland in Missouri and Kansas. In Indian Territory its border follows the valley of the Grand River to the Boston escarpment. Beyond that point the lowland continues along the Arkansas River and forms the southern border of the Boston Mountains, the exact regional limits of which are not yet determined sufficiently to be defined.

CHAPTER III.

By George I. Adams.

GENERAL GEOLOGY.

The general geology of the Ozark region has been made known principally through the reports of the Missouri and Arkansas geological surveys. For the broad discussion of the ore deposits it is necessary to have clearly in mind the salient features of the geology. These may be obtained from the reports of the geological surveys of the above-mentioned States, and are here summarized. The geological section has not been completely made out for the region, inasmuch as detailed work has not been extended over sufficient area. The most confusion is found in the section of the Cambro-Silurian rocks, but as related to the ore deposits these rocks may be regarded as essentially a unit.

As shown upon the accompanying geological map (Pl. X, in pocket) the formations have a somewhat concentric distribution. The oldest rocks are found in the St. Francis Mountains, while those younger and geologically higher are found farther out on the borders of the plateau. The basal member of the region is the pre-Cambrian. Rocks of this age, all of which are igneous, are exposed in the St. Francis Mountains, where they protrude as mountain masses through the sedimentary formations, which were deposited over them and subsequently eroded from their summits. Around this area and dipping away in all directions are found Cambrian formations, which have not been differentiated except in a small area. The Ordovician or Lower Silurian rocks are exposed over a large area in the eastern part of the Ozark Plateau, especially in southeastern Missouri. The Silurian is represented along White River in Arkansas. The Devonian formations form a narrow belt bordering the Ordovician along the Missouri and Mississippi rivers. On the borders of the Ozark region the Carboniferous rocks are well represented. A few dikes of post-Paleozoic and probably pre-Cretaceous age cut the sedimentary beds. In the following discussion the various formations have been grouped according to their relations to the ore deposits.

IGNEOUS ROCKS.

Igneous rocks constitute but a small factor in the geology of the Ozark region. There are but three areas in which they are known to occur. The most important of these is in the St. Francis Mountains, in southeastern Missouri, sometimes referred to as the Iron Mountain region. The rocks are of pre-Cambrian age. The second area is found in the Cherokee Nation, in the northeastern part of Indian Territory, near the mouth of Spavinaw Creek, where there is a granitic dike about one-fourth of a mile long. The third area is a very minute one on the southern border of Camden County, in Missouri. The rock is a pegmatite dike, the actual exposure of which covers only a few square yards. The rocks of the second and third areas are of post-Carboniferous age.

ST. FRANCIS MOUNTAINS (PRE-CAMBRIAN).

In the Iron Mountain region the exposures of igneous rock have the form of rounded bosses and domes which protrude through the sedimentary series and constitute a scattered group of irregular form, and which are embraced within an area of about 70 miles square. The principal portion of these exposures is within a radius of 10 miles or so from Iron Mountain. The rocks which constitute this formation are granites and porphyries with several varieties of basic rocks that occur as dikes.

KNOB LICK GRANITE AND IRON MOUNTAIN PORPHYRY.

The name Knob Lick has been given to the granite, and the porphyry is known as the Iron Mountain porphyry.[1] There is, however, no distinct line of division between them, and they represent phases of the same mass which have resulted from the differing conditions of cooling and solidification. The porphyry is the portion of the magma which cooled nearer the surface and under less pressure and has a finer texture, while the granite represents the deeper portion which solidified more slowly and is coarser. Subsequent erosion has resulted in the exposure of both phases. The age assigned to them is pre-Cambrian. This is attested by the fact that the sedimentary rocks which overlie them are Cambrian in age, and there is no sign of contact metamorphism, such as would have occurred had the igneous rocks been intruded into them. Moreover, there is evidence of a long period of erosion previous to the deposition of the stratified series which overlie them and which contain in their basal members fragments derived from the igneous rocks. The exposures of the pre-Cambrian formation represent but a small portion of the great basal member of the region. It is interesting to note that a deep well at Carthage reached it at a depth of 1,745 feet. The contour of the igneous rocks, as exposed, does not retain the ruggedness of their buried surface, since, during the process of erosion of the stratified rocks from the crests and slopes of the peaks, they have likewise been reduced considerably in altitude and to a more rounded outline.

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[1] Crystalline rocks of Missouri, by Erasmus Haworth: Missouri Geol. Survey, Vol. VIII, 1895, pp. 81–220. Mine La Motte sheet, by C. R. Keyes: Missouri Geol. Survey, Vol. IX, 1896, p. 18.

SPAVINAW DIKE (POST-CARBONIFEROUS).

The igneous rock found on Spavinaw Creek in Indian Territory lies about 35 miles west of the Arkansas border, and 6 miles from the junction of the creek with Grand River.[1] It is on the north side of the stream, three-fourths of a mile west of Spavinaw post-office. Although the dike is probably continuous for a distance of a quarter of a mile, yet the actual exposures vary from 200 to 400 feet in length, with intervals covered by detrital material. The width of the dike is approximately 50 feet. The area in which it occurs has the structure of an anticlinal fold, across which Spavinaw Creek has cut its valley. Above and below this point the creek has its channel in the Mississippian limestones, but as a result of the fold the underlying Ordovician strata are exposed to a depth of 200 feet. The axis of the anticline extends N. 30° E., and the dip of the strata on either side is from 5° to 10°. The dike cuts the Silurian rocks along the axis of the anticline, and was evidently intruded at the time of the folding. Since the Mississippian strata conform to the structure of the fold it is presumable that the dike is of a later date than these rocks. Probably it is post-Carboniferous and pre-Cretaceous in age, being thus referred to the period of disturbance which produced the system of folds and faults to which the region in general was subjected.

CAMDEN COUNTY DIKE (POST-CARBONIFEROUS).

The third area of igneous rocks, which is found on the southern border of Camden County, Mo., is so small that it was long overlooked by geologists. It was discovered by Shepard, and has been described by Winslow.[2] It is a dike consisting of a graphic granite or pegmatite. It occurs in an area of magnesian limestones with which are associated some sandstone beds. These are normally undisturbed, and lie nearly horizontal, but in the vicinity of the pegmatite dike there are local steep dips and lines of folding developed in an irregular way. The exposed area of the dike is but a few yards in extent. As to the date of its origin there is necessarily much uncertainty. The intrusion probably never reached the surface. That it was post-Ordovician is evident, and Winslow has been inclined to assign it to the post-Carboniferous disturbance which took place over this area. It may accordingly be of the same age as the dike on Spavinaw Creek in Indian Territory.

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[1] Geological reconnoissance in the coal fields of the Indian Territory, by N. F. Drake: Proc. Am. Philos. Soc., Vol. XXVI, p. 338.

[2] Missouri Geol. Survey, Vol. VII, 1894, p. 432.

CAMBRIAN.

SOUTHEASTERN MISSOURI SECTION.

In the vicinity of the St. Francis Mountains, or the Iron Mountain region, as it is sometimes called, the Cambrian rocks have been studied and mapped over the area of the Mine La Motte sheet by C. R. Keyes.[1] They there present the following section in ascending order.

La Motte sandstone.—This term is applied to the lowest formation, which has a thickness of about 200 feet. At its base is a conglomerate made up of rounded pebbles and bowlders, derived from the underlying pre-Cambrian. The sandstone is a rather soft, compact, medium-grained rock, containing more or less calcareous and magnesian material as cement. The color varies from buff or white to darker shades. It grades locally into limestone, both horizontally and vertically.

Fredericktown limestone.—This formation is largely a dolomitic limestone, having an approximate thickness of 250 feet. It has two phases, which are quite distinct. The lower one is a grayish limestone with some sandy and shaly layers, while the upper is a buff dolomite relatively free from sandy material.

Lesueur limestone.—The succeeding formation is a very cherty dolomite, which attains a thickness of 250 feet. The chert occurs as nodules and layers, and upon the removal of the limestone is left as surface material.

The formations above described constitute an incomplete section of the rocks of the district, and may not include all the Cambrian. In a report by Winslow[2] covering a somewhat larger area and including that described by Keyes, the same section was discussed under a different nomenclature. Above the pre-Cambrian Winslow distinguishes the Iron Mountain conglomerate, the La Motte sandstone, the St. Joseph limestone, and the Potosi limestone. These may be the equivalents of the section as described by Keyes, who did not use the term St. Joseph limestone, and whose report, extending over a smaller area, did not include the locality of Potosi.

SILURIAN.

LOWER SILURIAN OR ORDOVICIAN.

NORTHERN ARKANSAS SECTION.

In northern Arkansas the Ordovician is represented by the rocks which were described by the Arkansas survey as Lower Silurian, excepting the upper part of the St. Clair limestone as originally defined.[1] The section is as follows:

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[1] Missouri Geol. Survey, Vol. IX, 1896.

[2] The disseminated lead ores of southeastern Missouri: Bull. U. S. Geol. Survey No. 132, 1896.

General section in northern Arkansas.

	Feet.
Polk Bayou limestone	75 ±
Izard limestone	280 ±
Saccharoidal sandstone Magnesian limestone Chert Sandstone, etc	1,700 ±

The stratigraphy of the lower part of this section has never been worked out in detail. The Polk Bayou and Izard limestones, which are the highest members of the section, are not always present, especially in the northwestern part of the State, where the upper member exposed is the Saccharoidal sandstone, the absence in such cases being probably due to pre-Carboniferous erosion.

The lowest formations of the Ordovician have not been described, except in a general way, and the age of some of the beds usually included has not been determined. A deep well near Batesville passed through 1,515 feet of strata below the Saccharoidal sandstone without reaching the pre-Cambrian.

Fossils were collected near Smithville, Lawrence County, Ark., and determined by Mr. Charles Schuchert as follows:

- Gasteropoda:
  - *Eccgliopterus* sp. near *Ophileta ? disjuncta.* Billings.
  - *Maclurina* with large horn-shaped opercula. This form is between *Maclurina oceana* and *M. affinis.* (Billings.)
  - *Trochonema* sp.
  - *Liospira.* Two species.
- Cephalopoda:
  - *Orthoceras* sp. A small smooth form.
  - *Orthoceras* sp. Annulated.
  - *Endoceras* siphuncle.
  - *Eurystomites* sp. A very small species.

These forms are characteristic of the Lower Ordovician, the fauna corresponding to that of the Calciferous formation of the New York section. The exact relations of the Lawrence County beds to the higher portion of the section as made out by the Arkansas geologists are not yet determined.

Saccharoidal sandstone.—This sandstone, so called because of its having the appearance of sugar, is a bed of friable sandstone which crumbles readily into loose sand. Its normal color is usually white, although it often has a brown staining on the surface. It is known to reach a thickness of 125 feet. Its component strata are of varying thickness, from a few inches to a number of feet, and it is frequently false bedded. In places it is cut by a network of white seams of quartz a fraction of an inch thick. Since these weather slowly, the rock in such places has a honeycombed appearance. Sometimes a quartzitic phase is developed, and at certain localities the sandstone contains nodules of flint. These are usually concentrically banded, showing black and white layers.

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[1] Marbles and other limestones, by T. C. Hopkins: Rept. Arkansas Geol. Survey for 1890, Vol. IV, 1893. Paleozoic faunas of northern Arkansas, by H. S. Williams: Rept. Arkansas Geol. Survey for 1892, Vol. V, 1900, p. 277.

Izard limestone.—This limestone, named from Izard County, is exposed over approximately the same area as the St. Clair, below which it lies. It is a smooth, fine-grained, compact, homogeneous rock, nonfossiliferous, and evenly bedded. It is usually of dark-blue color, but varies to buff, light gray, and almost black.

Polk Bayou limestone.—This limestone was included in the original description of the St. Clair, named from the St. Clair Springs, northeast of Batesville, Ark.[1] The name St. Clair was later restricted in its application to the lower part of the formation as originally defined.[2] In the latest report of the Arkansas survey the name St. Clair is used for the upper portion, which is of Upper Silurian age, and the lower part has been given the name Polk Bayou.[3]

The Polk Bayou limestone outcrops in an irregular belt along the valley of White River from Batesville westward for a distance of about 80 miles. It is highly crystalline, occurs in heavy stratified layers, and varies from light gray to chocolate brown. In the region of the manganese deposits it is stained by this mineral, which lies immediately above it.

SOUTHEASTERN MISSOURI SECTION.

The section of the Ordovician rocks in Missouri is in considerable confusion. The earlier workers, Swallow, Shumard, Broadhead, and their associates, included the stratified beds below the Trenton in a single series, which they called the Magnesian series and to which Broadhead later gave the name Ozark series. Swallow established the following sections in descending order:

First Magnesian limestone.
First Saccharoidal sandstone.
Second Magnesian limestone.
Second Saccharoidal sandstone.
Third Magnesian limestone.
Third Saccharoidal sandstone.
Fourth Magnesian limestone.
Fourth Saccharoidal sandstone.

The difficulty in recognizing in widely separated localities formations having characteristics so similar has led to the partial abandonment of this classification. The work which has been done subsequently, however, is very incomplete and does not cover the entire section of the Ordovician.

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[1] Rept. Arkansas Geol. Survey for 1890, Vol. I, 1891, p. 102.

[2] On the age of the manganese beds of the Batesville region of Arkansas, by H. S. Williams: Am. Jour. Sci., 3d series, Vol. VIII, 1894, p. 325.

[3] Paleozoic faunas of northern Arkansas, by H. S. Williams: Rept. Arkansas Geol. Survey for 1892, Vol. V, 1900, p. 285.

This series of rocks has been studied near the center of the area of their exposure, along Big Piney and Gasconade rivers, and along Current River, by Frank L. Nason,[1] who worked out the stratigraphy as follows:

Roubidoux sandstone.—The name Roubidoux is applied to a sandstone which overspreads the Ozark region, from Cabool to Gasconade City and from Salem to Doniphan. This is believed to be the equivalent of the Pacific and Crystal City sandstones, which, according to the old nomenclature, were considered to be the First Saccharoidal.

Gasconade limestone.—The name Gasconade limestone has been given to a great series of limestone beds below the Roubidoux sandstone, interstratified with relatively thin sandstones. From a study of the section along the Osage River, this formation was further subdivided by Winslow as follows:

Gasconade limestone	Jefferson City limestone. Moreau sandstone. Osage limestone. Cole Camp sandstone. Proctor limestone.

UPPER SILURIAN.

NORTHERN ARKANSAS SECTION.

Cason shale and St. Clair limestone.—The upper portion of the beds in northern Arkansas, originally described by the Arkansas survey as the St. Clair limestone, should be referred to the Upper Silurian. This reference was made by H. S. Williams,[2] who examined the section and studied the fossils and the beds. He subdivides the St. Clair limestone and calls the lowest division the Polk Bayou limestone. Above it he distinguishes the Cason shale, which is succeeded by the St. Clair limestone proper. At the top of the Polk Bayou limestone he recognizes a line of unconformity, or at least either an interval of erosion or a cessation of deposition. Fossils collected from these horizons determine the Polk Bayou limestone to be of Trenton age, while the overlying beds are referred to the early Niagara. He correlates the Polk Bayou limestone with the Nashville group of Tennessee, and the St. Clair limestone with the Waldron beds of Indiana and the Clinton-Niagara fauna of New York.

DEVONIAN.

The typical Devonian beds are found only along the northern and eastern borders of the Ozark region. In southeastern Missouri, in the vicinity of Grand Tower, on the Missouri River, rocks are exposed which have long been referred to the Devonian. This formation, with some variations, extends around the northern border of the area of Cambro-Silurian rocks as far west as Jefferson. The Devono-Carboniferous shale, which is found in typical development on the southern and western borders of the plateau, represents the encroachment of the sea which took place at the close of the Devonian. This transgression was progressive, and in the southeast seems to have begun before the close of the Devonian, as is shown by the close resemblance of the Devono-Carboniferous shale to the Black shale of Tennessee. On passing westward the beds, which are continuous, assume more of a Carboniferous facies. This becomes still more marked along the outcrop from the west to the northeast, where the rocks are recognized as Kinderhook. These beds are discussed more fully under the Carboniferous.

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[1] The iron ores of Missouri: Missouri Geol. Survey, Vol. II, 1892.

[2] Loc. cit.

CARBONIFEROUS.

LOWER CARBONIFEROUS OR MISSISSIPPIAN.

ARKANSAS SECTION.

Devono-Carboniferous shale and Sylamore sandstone.—In northern Arkansas the basal members of the Mississippian were named the Eureka shale and Sylamore sandstone by the Arkansas survey,[1] and were at first doubtfully referred to the Devonian. In a recent article[2] the typical Devono-Carboniferous shale is referred to the Carboniferous and is considered as equivalent to the basal portion of the Kinderhook. These shale and sandstone formations have not been studied closely enough to determine their exact relations, for where one occurs typically the other is usually absent or concealed. The Devono-Carboniferous shale is exposed in the northwestern part of Arkansas and was named Eureka from the locality of Eureka Springs.[3] It varies considerably, usually having a thickness of about 50 feet, with a maximum of 70 feet. Eastward it thins out, and its place is probably taken by the Sylamore sandstone. The latter bed is a variable formation which locally has a thickness of 40 feet, although it usually is much thinner and is in places entirely absent. The Sylamore sandstone has the same stratigraphic relations as the shale. It is imporant as being the horizon of the phosphate deposits of northern Arkansas. The Devono-Carboniferous shale has been described as occurring in the northeastern part of Indian Territory at several localities where, as a result of the slight folding and faulting of the strata, streams have cut through the Mississippian limestones down to the Ordovician. In these places the Sylamore sandstone is absent. In the extreme southeastern part of Missouri areas of the shale are found along Elk River and

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[1] Geology of Washington County, by F. W. Simonds: Rept. Arkansas Geol. Survey for 1888, Vol. IV, 1891, p. 26.

[2] Paleozoic faunas of northern Arkansas, by H. S. Williams: Rept. Arkansas Geol. Survey for 1892, Vol. V, 1900, p. 317.

[3] See footnote 4 on page 49.

Sugar Creek. It has not been mapped continuously along the line of contact of the Lower Carboniferous and Cambro-Silurian rocks in Missouri, but is described as occurring at several points, notably in Greene County, and has been found at intervening localities which have been visited. The question of the persistence of this shale is a matter of much importance, since it has a definite relation to the conditions of ore deposition. In the northwestern part of Arkansas deep wells have been sunk with the hope of finding oil or gas, and the shale in these is said to have a thickness of from 50 to 70 feet, which corresponds with that of the nearest exposures. In the deep wells around Joplin, in southeastern Missouri, the shale is thin and sometimes absent, according to the reports of the drillers in that locality.

Boone formation, including the St. Joe limestone.—In northern Arkansas a large area is occupied by the Boone chert and limestone.[1] It includes the St. Joe limestone, which lies at its base, and which was distinguished and mapped later. This formation succeeds the Devono-Carboniferous shale. The fauna of the St. Joe limestone is stated by Williams to be typically Kinderhook.[2] If so, it is perhaps the equivalent of the Chouteau in Missouri, but as yet it can not be definitely correlated. The upper portion of the Boone formation is found over a large part of the western portion of the plateau region, and extends into Indian Territory, where it was recognized by Drake in the report of his reconnaissance. Farther northward, in Missouri, the probable equivalents of the upper part of the Boone formation have been mapped in Greene County by Shepard as the Upper and Lower Burlington limestones.

The formations which constitute the basal terrane of the Boston Mountains, and whose northward-facing escarpments rise above the plain of the Boone formation, consist of shales and sandstones aggregating about 1,300 feet in thickness. They are described below.

Fayetteville shale.—The lowest member is the Fayetteville shale, which has a maximum thickness of 300 feet. It is a black, carbonaceous, fissile shale, containing dark-blue concretionary limestones, which at several localities form quite definite horizons near the middle of the formation. The Spring Creek limestone, described from near Batesville, is thought to be the equivalent of these beds.

Batesville sandstone.—Above the Fayetteville shale is a bed of sandstone, which in places has a thickness of 200 feet. It has been described as the Batesville sandstone, and is known to vary in lateral extent, although it is represented quite uniformly over a large area. Succeeding it is the Boston group, from which it has not been generally distinguished in mapping by the Arkansas survey.

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[1] Geology of Washington County, by F. W. Simonds: Rept. Arkansas Geol. Survey for 1888, Vol. IV, 1891, p. 27.

[2] Paleozoic faunas of northern Arkansas, by H. S. Williams: Rept. Arkansas Geol. Survey for 1892, Vol. V, 1900, p. 331.

Boston group.—This term has been applied to a number of sandstone, shale, and limestone formations described under particular names by Mr. F. W. Simonds. The lowest of these is called the Marshall shale, and the maximum thickness assigned is 250 feet, although it is known to thin out laterally, and in places it may be absent. It is succeeded by the Archimedes limestone. This limestone varies from a few feet to 80 feet in thickness. Above it lie the Washington shales and sandstones, which are likewise variable in character. The next succeeding formation is the Pentremital limestone. The various exposures of it vary from a few feet to nearly 100 feet in thickness, and in places it is separated into two beds by sandstones and shales. Succeeding it is a 100-foot bed of coal-bearing shale. The highest member of the group is the Kessler limestone, which is found well represented at only a few places. The various formations which constitute the Boston group have not been mapped over a large area, and it is possible that they can not be identified except in a local area.

SOUTHWESTERN MISSOURI SECTION, GREENE COUNTY.

The basal division of the Mississippian series in southwestern Missouri should be referred to the Kinderhook, although it does not represent a typical development of that formation. In Greene County,[1] as described by Shepard, it consists of limestones, shales, and sandstones. The limestones and shales predominate in a large part of the area. In going southward, the sandstones thin out and are replaced by shales.

Devono-Carboniferous shale.—This formation was called Eureka shale by Shepard. As represented in Greene County it is relatively thin, the best exposures showing a thickness of only about 5 feet. It retains, however, the same general characteristics as in northern Arkansas, and the exposures are believed to be directly continuous.

King limestone.—The bed of limestone to which this name is given varies from 1 foot to 15 feet in thickness. It is a soft, fine-grained, ashy-gray rock, made up of thin alternating layers of hard and soft material. It decomposes readily and is not conspicuously exposed.

Sac limestone.—This is a massive, purplish-gray or drab magnesian limestone, mottled with greenish patches. It is absent in some localities, but attains a thickness of 18 feet in some sections. Locally it is cherty, and it also merges into soft ferruginous varieties of limestone.

Phelps sandstone.—This bed nowhere exceeds 4 feet in thickness, but has very marked characteristics. It varies from a soft, irregularly bedded sandstone of a watery-green color to a quartzite-like stratum. It frequently contains pebbles of chert, and there are many fish teeth found in it, all of which have a waterworn appearance. These facts are evidence that it was a beach formation.

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[1] Geology of Greene County, by Edward M. Shepard: Missouri Geol. Survey, Vol. XII, Pt. I, 1898, pp. 13-236.

The above-described formations were referred by Shepard to the Devonian. They are, however, faunally related to the succeeding formations, which he considered Lower Carboniferous.

Louisiana limestone.—This bed is nowhere very thick, and has a limited exposure. It is a very hard limestone, divided into many layers, and has a total thickness of about 8 feet.

Hannibal sandstone and shales.—This formation consists usually of an upper yellowish sandstone, penetrated everywhere by worm-like borings, and a lower bluish compact shaly member. It has a thickness of from 10 to 90 feet. The sandstone, which in some places is 25 feet thick, is locally absent. The tube-like impressions are thought to be the remains of fucoids or seaweeds. The shales vary in color from grayish to blue. They are softer where they have an arenaceous character, while the silico-magnesian variety is hard and separates into hard slabs suitable for flagging.

Chouteau limestones.—The limestones which constitute this formation are fine-grained, compact, heavy-bedded, and buff to yellow in color. The thickness varies from 3 to 30 feet. Their structural characteristics indicate a gradual transition from shallow water to deep-sea deposits.

In a recent article by Stuart Weller[1] the faunas of the basal division of the Mississippian in Greene County are reviewed and shown to be Kinderhook in age. The formations described by Shepard are correlated as shown in the accompanying table. It will be noted that the formations defined by Weller are the equivalents of those mapped by Shepard:

Shepard.	Weller.
Chouteau limestone	Pierson limestone.
Hannibal shale Louisiana limestone	Northview shale and sandstone.
Phelps sandstone Sac limestone King limestone	Sac limestone.
Eureka shale	Eureka shale.

The Burlington is divided by Shepard into the Upper and Lower Burlington, although there is no very definite line of demarcation.

Lower Burlington limestone.—The basal portion of the Lower Burlington is a heavy-bedded, bluish or slate-colored, fine-grained, hard limestone, often interspersed with lenticular masses of chert, which, toward the south, take the form of great rolls of chert between beds of limestone. The upper beds are made up of from 5 to 20 feet of yellowish-white, very hard chert, which breaks with a conchoidal fracture. The formation as a whole varies with its lateral extent, and its thickness averages about 70 feet.

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[1] Correlation of the Kinderhook formations of southwestern Missouri: Jour. Geol., Vol. IX, No. 2, pp. 130-148.

Upper Burlington limestone.—The lower beds assigned to this formation consist of 50 to 80 feet of shaly limestones, which outcrop in shelving ledges. Above them is rather coarse-grained, crystalline limestone, of soft-gray color, and 60 to 100 feet thick. It includes small lenticular masses of chert, but is locally free from it. The limestones frequently exhibit characteristic stylolitic structure or suture joints. The heavy beds furnish good quarry stone. The highest portion of the formation consists of alternating beds of shaly limestone and chert, and reaches a thickness of 40 feet.

Fossils have been found in both Arkansas and southwestern Missouri indicating the presence of the Keokuk formation, but it has as yet not been differentiated from the Burlington.

MISSISSIPPI RIVER SECTION.

Along the Mississippi River the Burlington, Keokuk, Warsaw, St. Louis, and Chester divisions of the Lower Carboniferous are typically represented. They are not known to carry ores, and no special description is here given.

UPPER CARBONIFEROUS.

The transition from the Lower Carboniferous or Mississippian to the Upper Carboniferous rocks, as represented in the various parts of the field, is marked by an unconformity and a considerable period of erosion. In the Boston Mountains the lowest member is the Millstone grit. Continuing westward and northward, and following the curving boundary of the formation into Kansas and Missouri, we find that the lowest member is the Cherokee shale, a much higher formation. The Millstone grit rests upon the Boston group, while the Cherokee shales rest upon the Mississippian limestones. It will thus be seen that the Fayetteville shale and Boston group have probably been eroded, or may never have been deposited along the northwestern margin of the Ozark Plateau.

Millstone grit.—Millstone grit is the term used by the Arkansas survey for a series of sandstone beds interstratified with shales at varying intervals, the thickness of the formation being reported as about 400 feet.[1] The name Millstone grit was applied because of the occurrence of quartz grains and small quartz pebbles in the sandstone, making it conspicuous and easily distinguishable from the underlying formations. In Indian Territory the rocks which constitute the Boston Mountains are known to be represented by a much thinner series of strata, and no strict correlation has been attempted. Drake has not differentiated them in his mapping, although he has made reference to the occurrence of some of the more typical formations, and has reported the Millstone grit, or a conglomerate or coarse-grained sandstone which resembles it, as far north as the border of Kansas. He reports it as thinning out northward, or being covered by the overlap of higher formations.

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[1] This term was used by David Dale Owen in his Geological Reconnoissance of the Northern Counties of Arkansas, 1857-1858; see p. 137.

Graydon sandstone.—In southwestern Missouri there are remnants of Coal Measures rocks lying upon the Mississippian limestones, to which the name of Graydon sandstones has been given.[1] In places these outcrops are a coarse conglomerate, and indicate by their relation to the underlying rocks the existence of irregularities produced by erosion. Inasmuch as they lie to the east of the main area of Cherokee shales and their conglomeratic nature is very marked, there is a possibility that they may be in part the equivalent of the Millstone grit, which, as a result of erosional unconformity, may there rest upon the Mississippian limestones.

Cherokee shales.—The Coal Measures rocks which succeed the Millstone grit are exposed along the western border of the Ozark region in Indian Territory, Kansas, and Missouri, and are in contact with the Mississippian limestones from the border of Kansas northeastward. The basal member consists of a bed of shales and sandstones about 450 feet thick, to which the name Cherokee shales has been applied.[2] It forms the lowland lying just west of the drainage of Spring River, in Kansas, and extending northeastward into Missouri to the vicinity of Sedalia, beyond which place it borders the Mississippian area in a narrow belt. The succeeding Coal Measures rocks in Kansas and Missouri dip away from the Ozark Plateau to the westward, and have a total thickness of about 2,000 feet.

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[1] Geology of Greene County, by E. M. Shepard: Missouri Geol. Survey, Vol. XII, Pt. I, 1898, p. 124.

[2] Erasmus Haworth: Univ. Geol. Survey of Kansas, Vol. I.

General geological section of the Ozark region.

AGE.	MISSOURI SECTION.		ARKANSAS SECTION.	CLASSIFICATION OF ROCKS.
TERTIARY.	Represented in southeastern Missouri.		Represented in eastern Arkansas.	
UPPER CARBONIFEROUS.	Cherokee shales; Haworth Graydon sandstone; Shepard.		Millstone grit.	Undifferentiated shales and sandstones of the Carboniferous system.
LOWER CARBONIFEROUS.	Chester St. Louis Warsaw Keokuk	Mississippi River section.	Boston group; Batesville sandstone; Fayetteville shale of Arkansas survey.	
	Upper Burlington; Shepard Lower Burlington; Shepard		Boone chert and limestone, including the St. Joe limestone of Arkansas survey.	Limestones of the Mississippian series.
	Pierson limestone; Weller			Black shales of the Devono-Carboniferous system.
	Northview shales and sandstone; Weller.			
	Sac limestone; Weller			
	Eureka shale		Sylamore sandstone and Eureka shale of Arkansas survey.	
UPPER SILURIAN.	Either not represented or not differentiated.		St. Clair limestone; Williams. Cason shale; Williams.	Limestones and sandstones of the Cambro-Silurian system.
LOWER SILURIAN OR ORDOVICIAN.	Trenton Hudson River Roubidoux sandstone; Nason Gasconade limestone; Nason Lower limits not given.		Polk Bayou limestone, Izard limestone, Saccharoidal sandstone, Magnesian limestone, cherts, etc., of Arkansas survey.	
	Lesueur limestone; Keyes Fredericktown limestone; Keyes. La Motte sandstone; Keyes		Either not represented or not differentiated.	
ARCHEAN.	Iron Mountain porphyry Knob Lick granite		Not represented	Pre-Cambrian crystallines.

SUMMARY.

GROUPING OF THE FORMATIONS IN RELATION TO THE ORE DEPOSITS.

For the purpose of discussing the lead and zinc deposits of the Ozark region, the geological formations may be grouped into units which may be readily distinguished in the field by their lithologic characters (see last column of table above). These are shown on the accompanying general geological map (Pl. X, in pocket) and are described and designated as follows:

Pre-Cambrian crystallines.—These make up the basal member of the section, and are found exposed in the St. Francis Mountain region. They include the Knob Lick granite and the Iron Mountain porphyry, which are probably of Archean age.

Cambro-Silurian limestones and sandstones.—This series consists essentially of magnesian limestones and dolomites, together with interbedded sandstones. Limestones form a large portion of the area over which the series is exposed. The lowest members of the series are found surrounding the pre-Cambrian area and are exposed on the flanks of the St. Francis Mountains. They dip away from the central portion of the Ozark Plateau, and their margins are buried by later rocks. The series rests unconformably upon the pre-Cambrian beds. The formations which succeed it were deposited after a period of extensive erosion, although the unconformity which marks this erosion is not characterized by sharp local irregularities. In these formations are the lead and zinc deposits of the Southeastern and Central Missouri and North Arkansas districts.

Devonian.—The formations referred to the Devonian, which outcrop along the Mississippi and Missouri rivers, as shown upon the map, are not known to be ore bearing and are not important factors in the problems of ore deposition as here discussed.

Devono-Carboniferous shale.—The formations included in this group are the transitional beds which mark the close of the Devonian interval and the encroachment of the Carboniferous. They have been described as the Eureka shale and associated beds in Arkansas and as the various members of the Kinderhook in Missouri. The group is essentially a shale formation, but presents considerable variation in lithological character in different portions of the area, including local development of sandstones, shaly limestones, and thin-bedded limestones. The outcrop of the group forms a narrow belt bordering the Cambro-Silurian area, and separating it from the succeeding formation. This is generally regarded as a barren zone, but bears an important relation to the problems of ore deposition.

Mississippian limestones.—These limestones outcrop over the western and southern part of the Ozark Plateau. They have been described in northern Arkansas as the Boone chert and limestone, and in Missouri as the Upper and Lower Burlington. The formation consists of interbedded crystalline limestones and cherts, with local exceptional developments of the chert. The Southwestern Missouri or Missouri-Kansas lead and zinc district lies within the area of this formation. These limestones rest conformably on the Devono-Carboniferous, and both the stratigraphic and paleontologic evidence points to a simple progressive change in sedimentation without, for this region, any marked physical break. The limestones are characteristically nonmagnesian and largely holocrystalline. The lower member of the series is a harder, more massive, and normally a less cherty limestone, though it carries a peculiar and heavy bed of chert at the top; the upper is thinner bedded and more cherty. It is not always possible to separate the two in drill sections, but in the field they are quite easily distinguished. The lower member is the thinner, ranging from 30 to 100 and averaging 50 to 60 feet in thickness. It is especially important along the eastern border line of the Carboniferous area, where it outcrops and has been mapped and studied by Shepard.[1] The upper limestone forms the surface rock over most of the area colored on the accompanying maps as Mississippian limestones. It is the common country rock of the Southwestern district.

In Arkansas the same limestones are developed, and to the whole group the term Boone chert has been applied. The Boone formations have been variously correlated with the Kinderhook, Burlington, and Keokuk divisions as developed elsewhere in the Mississippi Valley. There does not seem to be any general agreement in close correlation, and, as the present work has developed nothing new bearing on this question, no attempt will be made at this time to establish the relations of the divisions found in this area to the divisions of the typical Mississippian section.

Undifferentiated Carboniferous shales and sandstones.—The formations of Mississippian age which outcrop in the northern escarpment of the Boston Mountains and lie above the Ozark Plateau, together with the Upper Carboniferous rocks along the west and north limits of the area, are here grouped together for convenience of discussion. They contain no important deposits of lead and zinc. The shale beds which are in contact with the Mississippian limestones are, however, important in relation to the problems of ore deposition, inasmuch as they form an upper limiting horizon to the circulation of the waters in the lower beds. In the Southwestern ore district they are separated from the underlying limestones by a notable unconformity which marks a period of elevation and land erosion of considerable length at some time subsequent to the deposition of the limestones. The erosion did not continue long enough to produce an even land surface, and in this particular stands in sharp contrast with the period which preceded the deposition of the Devono-Carboniferous. The influence of the later unconformity is shown in the irregular border of the Upper Carboniferous or Coal-Measures beds in the Southwestern district, and to some extent in the large number of outliers found beyond this border. Many of these outliers are represented on the accompanying map, but there are many others too small to be shown. The unconformity is shown by the presence of important bodies of shales and sandstones in troughs and basins in the limestone. It has been so generally recognized that it is hardly necessary to describe specific instances. The phenomena are, however, noted on succeeding pages in connection with the description of several of the mines.

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[1] Geology of Greene County: Missouri Geol. Survey, Vol. XII, Pt. I, 1898, pp. 103-111.

Tertiary.—To the southeast of the Ozark region the area of the Cambro-Silurian and Carboniferous rocks is limited by the overlying Tertiary. This formation bears no relation to the lead and zinc deposits. There are in the Ozark region proper certain old gravels, distributed in what seem to be ancient river channels, which have been doubtfully referred to the Tertiary. They have not been particularly studied as yet and their age is uncertain.

Recent.—The history of the region since deposition ceased has been discussed in connection with the physiography. It is significant that the region lies entirely outside the limits of Pleistocene glaciation, and that accordingly the breaking down and solution of rocks has been going on solely under the influence of subaerial erosion for a very long period of time. The exact time at which the last warping and fracturing took place is as yet uncertain. The disturbances most important in the present connection are certainly later than the Coal-Measures epoch of the Upper Carboniferous, and may be as late as the close of the Tertiary. Even if, however, they prove to have taken place at the latter date, it remains true that present conditions have been stable for a very long time. The existing conditions of surface and underground water flow, from the center of the dome outward, have long been established.

GENERAL STRUCTURE.

The Ozark region is usually considered to be one of practically undisturbed rocks. As already stated, it is essentially a low, broad dome with quaquaversal dips and peripheral monoclinal folds. An idea of the broader features of its structure may be gained from the accompanying cross sections (figs. 4 and 5). The dip of the rocks throughout the region is usually measured in feet per mile rather than in degrees. The general conception that the folding, fracturing, and faulting is slight is correct in so far as the actual displacement of beds is measured in feet and as compared with like phenomena in closely folded regions. The actual amount of work accomplished is, however, very great. Phenomena of folding, faulting, and, in particular, of fracturing and crushing are widespread and, as compared with the thickness of the strata, are very important. Slight folds and faults are common throughout the region and may be observed at very many points. It seems improbable that displacement is confined to the periphery of the plateau, as suggested recently by Professor Haworth.[1] Faulting is common there, as he has shown, but equally important flexing and faulting occur well up on to the dome. North of Springfield, in Greene County, there are well-developed faults of a hundred feet at least, and Shepard has traced them as far toward the center of the plateau as North View.[2] Winslow's mine descriptions show widespread evidence of slight faulting.[3]

During the present season Bain observed evidences of faulting at widely scattered points. It seems not improbable, in view of the little study which has been devoted to the Ozark Plateau and the conflicting accounts of its stratigraphy, that faults of some magnitude, as compared with the thickness of the beds, may prove to be relatively common.

In its character and trend the Ozark region is genetically related to the Arkansas Valley and Ouachita Mountains. Since the development of its principal structural features the region has been subjected to vertical oscillations and warpings. The effect of these movements has been to modify and accentuate the previous structure. The evidence of this is seen in the present warped surface of the old base-level plains. While it is possible to read in part the later structural history of the region from its physiographic aspect, yet, as to the character of the forces acting and the causes producing them, there is little definite knowledge. Keyes has suggested—and recently Haworth has stated the case with particular fullness and clearness—that the Ozark uplift was made by vertical movement producing peripheral tension faults. If this genesis be considered to require the intrusion of considerable masses of material under the area uplifted, there is at most only very meager evidence of it. If so large a mass of material as would be necessary to do this work had been intruded under so slight a cover, it is extremely probable that it

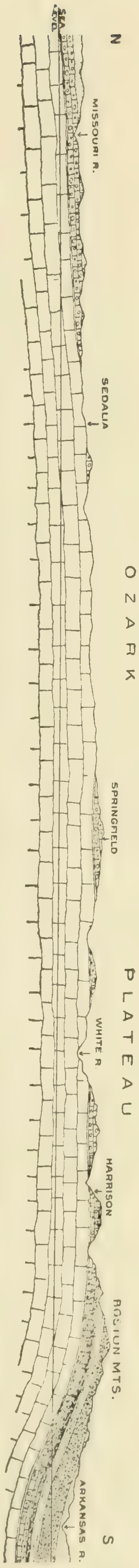

Fig. 4.—General north-south section across the Ozark Plateau and Boston Mountains through Sedalia, Springfield, and Harrison; by George I. Adams.

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[1] Relations between the Ozark uplift and ore deposits: Bull. Geol. Soc. America, Vol. XI, pp. 231-240.

[2] Geology of Greene County: Missouri Geol. Survey, Vol. XII, Pt. I, 1898, p. 155.

[3] Missouri Geol. Survey, Vol. VII, 1894, pp. 638, 694, 695, 696.

would have broken through to the surface in considerable quantity. The only intrusives known which could possibly be of importance in this connection are the small dikes found in Camden County, Mo., and along Spavinaw Creek, in Indian Territory, and at best their influence is wholly local. Drill holes which penetrate the crystalline floor show nothing to sustain the belief in any general intrusion, and, indeed, there is at all points a decided lack of evidence in favor of such an origin for the uplift. The prevailing conception that the Ozark region is dome shaped, although perhaps helpful, is apt to be misleading. While this term may describe its general configuration, it should be borne in mind that the structure is complex and can not be explained as the result of any one movement or period of oscillation. The faulting phenomena of the region have not been studied as yet in sufficient detail and widely enough to allow them to be grouped with reference to their relations to each other and to the region in general or to the causes producing them. However, a few general statements can be made. The most important and widespread action in the Joplin region in particular has been brecciation, and this can hardly have taken place except in connection with movement of beds one upon another in a manner resulting from compressive forces. Normal faults are present, and probably these are due to readjustments following the crushing. There is much detailed evidence of thrust action along the fault planes, but it is quite possible, if not indeed probable, that this is but the expression of the final stages of the normal faulting. Horizontal movement between individual beds has led to much fracturing, though it is not certain that the actual displacement has been great at any point, and the action may be looked upon as a movement of accommodation accompanying either the crushing or the later faulting. Slight folding is general, but close folding is rare.

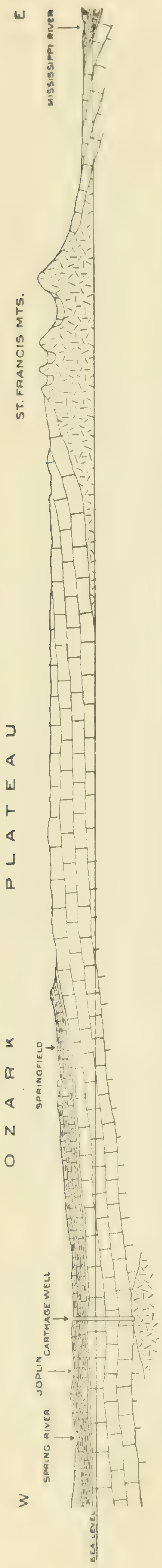

FIG. 5.—General east-west section across the Ozark Plateau through the St. Francis Mountains, Springfield, and Joplin; by George I. Adams.

The investigation of the nature and extent of these phenomena is at the present time incomplete, and it is only proposed here to indicate the reasons for believing that the Ozark uplift is not peculiar, but that it stands in genetic relation to the structure of the surrounding region.

CHAPTER IV.

By H. F. Bain.

RELATIONS OF ORE DEPOSITS TO THE CIRCULATION OF UNDERGROUND WATERS.

GENERAL PRINCIPLES.

It has long been recognized that ore deposits are, to a very considerable extent, the result of the circulation of underground waters. The work of recent years has tended both to reinforce this generalization and to extend the class of deposits to which it is applied. Furthermore, it has been emphasized recently and aptly by Van Hise[1] that the formation of ore deposits is, in the main, to be regarded as simply one phase of the general work of underground waters. This conception is fundamental to all modern work on the subject. It is clearly recognized that ores are also formed through other agencies—in particular by segregation from a molten magma or by direct deposition from a gaseous state by sublimation. Ores formed through such agencies, however, are exceptional. The briefest study is sufficient to show that such a genesis can not be assumed in the case of the lead and zinc ores below discussed, and that their origin is involved in the circulation of underground water. The reasons for this conclusion, which have been excellently summarized by Winslow,[2] lie mainly in the intimate association of the ores with large quantities of certain minerals, especially calcite and dolomite, not known to be formed to any notable extent except from solution. The study of the ores of the region, then, becomes primarily a study of the underground circulation, and there are certain general principles relating to the flow and work of water under ground which must be kept clearly in mind in order to understand the local phenomena.

CIRCULATION OF UNDERGROUND WATERS.

Cavities in rocks.—In ordinary terms rocks are solid bodies. Rocks, none the less, must be thought of as made up of individual discrete particles separated by larger or smaller spaces. The correctness of this conception is abundantly proved by experimental data. It frequently has been shown in studies of building stones, for example, that all rocks contain pore spaces. The amount of this space as compared with the total space occupied by a rock has been measured by means of the water which it will absorb. The open space in rocks, under conditions existing at or near the surface of the earth, varies within wide limits, ranging from a fraction of 1 per cent in certain granites and igneous rocks to 20 or 25 per cent in unconsolidated sands and 30 to 40 per cent in fine-grained clays.[1] The original pore space in rocks, in the case of sedimentaries, is the necessary result of the packing of the particles, of rounded, subangular, and angular form, in the course of their deposition, and in crystallines is the result of incipient stresses developed during the period of their crystallization.

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[1] Some principles controlling the deposition of ores: Trans. Am. Inst. Min. Eng., Vol. XXX, p. 151.

[2] Missouri Geol. Survey, Vol. VII, 1894, pp. 467-468.

It is necessary to keep in mind the difference between the porosity of a rock and its permeability.[2] The former refers to the open space in the rock, the latter to the amount of flow which may take place through it in unit time. A rock may contain much open space and still be practically impermeable as a result of the size or disposition of the cavities. Large spaces are favorable to permeability because of the smaller friction of the moving water on the walls of the cavities. All rocks are more or less permeable. Difference in the size and shape of the openings exerts so great an influence upon movement of the water, however, that of two rocks, one may be regarded, when compared with the other, as practically impervious. In general, the finer grained rocks are the less pervious, even when they include a larger total pore space.

Aside from the original pore spaces in rocks there are other openings, resulting from later stresses, which probably are more important in directing water circulation. The strata of the earth, from a variety of causes which it is beyond the purpose of this paper to discusss, are subjected, probably constantly, to stresses to which they tend to accommodate themselves. As a result of the low elastic limit of most rocks this accommodation under surface conditions is ordinarily by fracture, and the portion of the crust where fracture occurs is called the zone of fracture. In rocks deeply buried the accommodation is by "flowage." They are accordingly within the zone of flowage.[3] For present purposes the zone of flowage may be entirely neglected, since the phenomena of importance in a consideration of the lead and zinc fields relate entirely to the zone of fracture. The lower limit of the zone of fracture varies with the nature of the rocks, the time available for the deformation, and other factors, such as pressure, heat, moisture, etc.

Since the larger cavities formed by fracture are the ones more directly associated with ore deposits, they are the more important from the present point of view. The form of the cavity, except as it is changed by later solution, is dependent primarily upon the character of the rocks, and secondarily upon the degree and nature of stress operating in a given time. Brittle rocks break with a clear-cut fracture. Stresses in thin-bedded rocks are relieved by numerous small cracks and in thick bedded or massive rocks by fewer but more extensive cracks. Probably all fracturing is accompanied by more or less displacement, since it is the necessity for accommodation in position which produces the fracture. When, however, fracturing is accompanied by notable displacement the specific term faulting is used. As notable displacement results only from important stresses and accompanies notable fractures, faults are of great significance in marking out those fractures which are most extensive and consequently most important in directing underground circulation.

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[1] Principles and conditions of the movements of ground water, by F. H. King: Nineteenth Annual Report U. S. Geol. Survey, Part II, p. 98.

[2] Building and ornamental stones of Wisconsin, by E. R. Buckley: Bull. IV, Wisconsin Geol. and Nat. Hist. Survey, pp. 40–42, 68–69, 372–376.

[3] Principles of North American pre-Cambrian geology, by C. R. Van Hise: Sixteenth Ann. Rept. U. S. Geol. Survey, Pt. 1, p. 585 et seq.

Bedding planes between strata are natural division planes and under the slightest stress or the action of solutions they afford openings of even greater extent than fault planes. These openings are thin and tabular. Extensive fractures, such as are exemplified principally by faults and subordinately by joint planes, normally cut across the bedding planes of rocks and form openings similar in shape to those along bedding planes. Usually, as in the region under immediate discussion, these two sets of openings intersect.

Since different sorts of rocks accommodate themselves unequally to the same stress, it follows that there are differential movements between the individual beds, and that at bedding contacts between two sorts of rock, a shale and a limestone or a limestone and a chert, for example, the bedding plane becomes as well a faulting plane. It is in such a case all the more likely to serve as a plane of water circulation. The amount of actual slipping may be so small as to be measured in inches only, and yet there may be notable fracturing and an extensive plane may be opened to the circulating water.

Causes of circulation.—The cavities of rocks, of whatever origin, may be conceived of as being filled, or in cases partially filled, with the dilute solutions known collectively as ground water. This water is not usually dormant, but is constantly in motion, though that motion may be very slow. In most instances the motion is appreciable and results from the necessity of accommodation to unequal pressures. In so accommodating itself the water follows ordinary hydrostatic laws, the most important principle being summarized in the familiar adage that water tends to seek its level.

The primary cause of motion in underground waters is gravitation. The secondary and modifying causes are capillarity and thermal influences. Simple gravitation alone would give a circulation of the underground waters downward and laterally from the land to the sea, paralleling the surface circulation. It can not be doubted that the general average of water movement is in this direction. This general movement is, however, interrupted by temporary returns of the water to the surface. This occurs in three ways: First, in obedience to ordinary hydrostatic laws; second, as a result of capillarity; third, by definite upward movements resulting from thermal agencies. The most familiar phenomena indicating such a return of the water to the surface are those of springs and seepage.

Since the rate of flow of liquids through a given conduit is partially dependent upon their viscosity, and the latter is decreased by heat, it follows that heat operates not only to direct but actually to increase the amount of flow. In the region under discussion there is no evidence that more than ordinary heat has entered into the problem, and this factor accordingly may be neglected.

Surface of the ground water.—The upper surface of the ground water is very irregular and not a simple even plane as is that of the ocean, where the action of hydrostatic laws is practically unmodified by such limiting conditions as the form and size of the cavity in which the water is contained. In general, the ground-water level follows the surface topography, standing high in the hills and low in the valleys. It is greatly influenced by geologic structure, particularly by the distribution of pervious and impervious beds. The position of the ground-water level changes from time to time with the amount of rainfall and with any change in the attitude of the land with reference to near-by surface bodies of water. It is subject, in fact, to almost continual changes as a result of the downcutting of neighboring streams and other factors, and in mining regions is often notably depressed by pumping operations. It is an important horizon in relation to underground circulation and to ore genesis. Above it the cavities in rocks may be considered to be only partially filled with water and down to it comes, with a rapidity relatively great as compared with the motion below that level, that portion of the rainfall which, during and after a storm, sinks into the ground. Conditions above and below this level are radically different, particularly in all that relates to the chemical constitution of the ground water. It is a meeting place of waters of diverse composition and as a result a frequent plane of ore accumulation and change in character.

At first glance there would seem to be no good reason why water in the rocks should stand above the level of the water in the sea or the local controlling body of water, and the contrary would seem a contradiction of the laws of hydrostatics. The reason seems to lie partly in the influence of capillarity and, in the case of the fresh water of the land mass as compared with the salt water of the sea, partly in the greater weight and hence pressure of the sea water, but mainly in the influence of friction in retarding the downward journey of water through the rocks.

In capillary openings, which include many of the pore spaces in rocks, ordinary laws of capillary flow obtain. Under these laws water may move to a higher level than it would otherwise attain. This is doubtless quite important in producing the irregularities in the upper surface of the ground water.

Sea water or any saline solution is heavier bulk for bulk than fresh water or an aqueous solution less heavily charged with salts. If therefore a column of water under the land be balanced by a column of sea water the former may be longer than the latter. As a result of the greater weight of the sea water the fresh water may be sustained in the hills at an elevation considerably above sea level.

Probably the most important factor in producing irregularities in the surface of ground water is the great friction which exists between the moving water and the walls of the cavities and the consequent slow rate of travel. Cavities in rocks, so far as ground water moves through them, may be considered as either capillary or supercapillary. In the capillary cavities the flow is according to certain well-known laws, the most important result of which is that the motion is very slow. In supercapillary openings other laws obtain, but the motion is still slow. This slow motion is probably the principal factor in causing the water in the hills to stand above that in the valleys. This is shown by the close relation existing between the permeability of the rocks and the extent of the irregularities in the underground water level. The same thing is indicated by the influence of variations in rainfall on the height of the water under ground. The water is added from above faster than it is carried beyond this plane. In dry weather transportation or flow becomes greater than influx and the ground-water level sinks; in wet weather the reverse conditions obtain, and the level of the ground water rises. Normally, the level of ground water is at the plane where the two factors are in equilibrium, and, while the level of the ground water may remain constant, the course of the water itself is at the same time downward.

Course of underground waters.—The general motion is downward and toward the ocean if the waters of a continental mass as a whole be taken into account. This general motion may be made clear by illustrations of common conditions.

In traversing rocks from the point or points of ingress, for convenience of illustration conceived to be a plateau or hilltop, to the points of exit, here conceived to be a spring or horizon of springs in an adjacent valley, water does not use only the simplest and most direct course, but also utilizes the entire available cross section, even though this involves long detours, both vertical and horizontal.[1] Friction between underground waters and the walls of the cavities through which they flow is very important and increases very rapidly with decrease in cross section of the openings. It follows that of two routes open to water under a given pressure, that route will transmit more water which is made up of larger openings, though both routes will be utilized. There is accordingly a major flow through the larger openings, and in a sense pressure from the smaller openings toward the greater. This can not influence the course of the water to reverse its total movement, though it may temporarily cause the water to flow upward. Whether in any given case the total motion is from the small to the large cavities will depend upon the situation of the two sorts of openings with reference to the course of the water. This is made clear by the following diagram. Let the water entering the ground at the point *a* only be taken into account. The effective head evidently is measured by the vertical distance of *a* above the level of the sea, *h*–*i*. The water in part passes downward, following the various courses marked by dotted lines, and eventually finds its way to the sea as indicated. A portion follows the courses marked by heavy lines, which are intercepted by the fracture *b*–*d*, along which the water flows upward to the surface. This forms a spring at *b*, from which the water flows over the surface to the sea. In the case of the water following the line *a*–*c* there are at *c* two courses open to it, one, the longer route, via *d*–*b*, temporarily upward and thence over the surface, and the other toward *f*, where it makes its exit by seepage under the loose talus of the hillside and thence along the contact between the talus and the rock to the sea. If it be assumed that from *c* to *f* the course be along the smaller channels and from *c* to *b* along larger ones, it will be clear that more water will, in a given time, take the second course, because the friction is less. Thus, because of the greater amount of flow possible in a given time through the larger cavities, there is a motion toward them even at the expense of a temporary reverse of the main flow. If, however, the fracture is conceived to be at *a* rather than *b*, it is clear that the flow would be away from rather than toward it. So far, then, as the fracture planes lie in the line of motion of the water, and to some extent even when their course is across that line, they serve as trunk channels. There is a gathering of the water toward them and a major flow through them. Whatever phenomena of any sort result from the circulation of ground water are apt to be found in greater abundance and intensity in their

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[1] Theoretical investigation of the motion of ground waters, by C. S. Slichter: Nineteenth Ann. Rept. U. S. Geol. Survey, Pt. II, pp. 331-357.

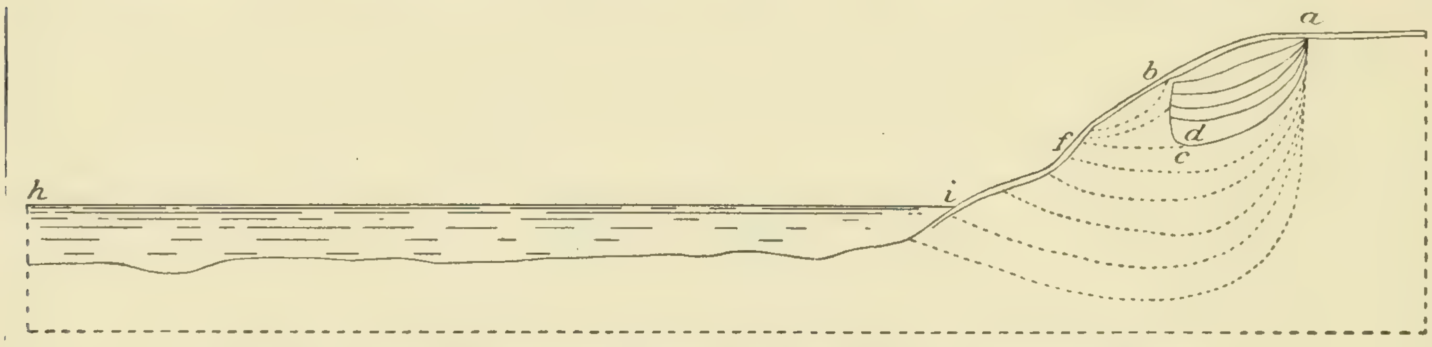

FIG. 6.—Sketch illustrating ideal circulation of underground water.

vicinity. This is a fact of great importance in relation to ore deposits, since experience shows that the deeper circulations find their way to the surface mainly along lines or zones of fracture.

Structural conditions influencing underground circulation.—While as a general process and in a broad way the movement of ground water may be considered as an average flow from the land toward the sea, interrupted by occasional returns to the surface, when the circulation is considered in detail it is seen that the underground waters circulate in separate and often sharply defined areas or basins. Deeper underground circulation has been studied mainly in connection with artesian wells. Except for Daubrée's two volumes[1] it is from papers on artesian wells that the best information regarding underground waters is obtained.[2] In breaking up the general circulation into a series of movements confined to limited depth and circumscribed areas, the geologic structure and the nature of rocks are important. This is due to the relative impermeability of certain sorts of strata, among which shales and slates take first place. Coarse sandstones and broken limestone allow ready passage of water, but shales interpose such difficulties to its passage that, even under considerable head, water will follow down the dip long distances to make its outlet along fracture planes, instead of passing directly upward through an overlying shale. The shale thus acts as an upper limiting bed in relation to the particular circulation. In the same manner a shale below an aquifer acts to limit the depth of circulation. To a less extent limestone, dolomites, cherts, and other beds may act in particular instances as upper or lower limiting members to a circulation. By the interbedding of permeable and impermeable strata the general underground circulation becomes divided into a series of separate circulations. When the area of intake lies at some elevation above the area of outflow artesian conditions are produced.

The general conditions in an artesian basin are illustrated in the figure below, redrawn from Norton.[3] It will be seen here that the St. Peters sandstone receives its supply from the Mississippi River some 500 feet above sea level. The sandstone dips to the southwest rapidly until at Des Moines it is reached at a depth of more than 2,000 feet. The water, however, rises in the well to the surface. It is also true that, though the sandstone has passed far below sea level and the water in it might be supposed to have come in contact with saline waters, it is uncontaminated. The firm Trenton limestone and shale above, with the Oneota below, have effectually protected it. The conditions are essentially similar to those in which a city water main passes beneath a river. Under such structural conditions underground circulation in a given district is independent of that in the surrounding areas. Conditions of this general type obtain in the Ozark region. A series of interstratified permeable and impermeable beds may become charged with artesian waters acting under different heads and having somewhat varied chemical composition. A fault plane or other fracture cutting across such a sequence and the mingling of the various waters afford favorable conditions for the precipitation of minerals carried in solution. This might, in a given case, produce an ore body.

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[1] Les Eaux Souterraines a l'Époque actuelle, by A. Daubrée, Paris, 1887.

[2] T. C. Chamberlin: Fifth Ann. Rept. U. S. Geol. Survey, pp. 131–173; Artesian wells of Iowa, by W. H. Norton: Iowa Geol. Survey, Vol. VI, pp. 115–428; Frank Leverett: Mon. U. S. Geol. Survey, Vol. XXXVIII, pp. 550–784.

[3] Iowa Geol. Survey, Vol. VI, p. 137.

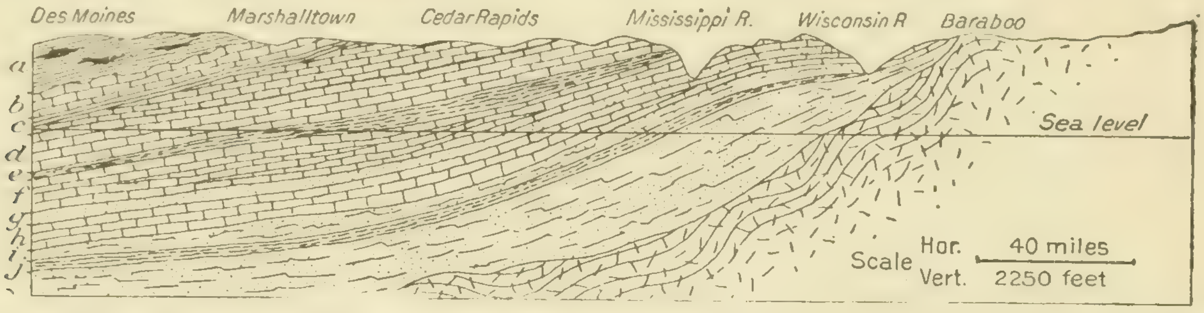

FIG. 7.—Geological cross section from Baraboo, Wisconsin, to Des Moines, Iowa. (After Norton.) *a*, Des Moines formation; *b*, Mississippian; *c*, Kinderkook; *d*, Devonian; *e*, Silurian; *f*, Hudson River group; *g*, Galena-Trenton; *h*, St. Peter; *i*, Oneota; *j*, St. Croix, including the Jordan, St. Lawrence, and Basal sandstone. The chief aquifers are the St. Peters, the Jordan, and the Basal sandstone. The line of junction of the Basal sandstone and the Algonkian is hypothetical.

WORK OF UNDERGROUND WATERS.

Solution.—Rain water as it falls on the ground after traversing the atmosphere, while relatively pure, carries in solution certain percentages of oxygen, nitrogen, carbon dioxide, and other atmospheric gases. As it passes through the vegetal mold covering the earth's surface and the belt of weathering lying above the ground-water level, there are reactions between the water itself and various materials held by it in solution and the salts with which it comes in contact. When, accordingly, it reaches and joins the ground water it has a composition still more complex than it had when it entered the ground. The ground water, by reason principally of the longer time during which it has been in contact with the rocks, is even more heavily charged with salts. Both the incoming water and that previously accumulated must be considered as complex dilute solutions. In fact, the entire circulating medium in the rocks is a dilute solution of variable composition. According to the modern theory of solutions, materials in that state exist in a dissociated or ionized condition. The molecules are broken up into fractional parts, which are known as ions. The degree of ionization varies with conditions and is dependent upon many factors. Pure water, by reason of the property of breaking up into hydrogen and hydroxyl ions in the presence of salts, is essentially a weak acid, and as such is capable of taking into solution certain quantities of the various salts contained in the rocks of the earth's crust. Increased solvent action may be brought about by anything which increases dissociation. Increased heat and pressure, while important influences of this character in general, can not have been operative in the Ozark region. The most important influence in promoting dissociation in the ore-bearing solutions of the Ozark region was probably complexity of solution, since in mixtures of salts those without a common ion decrease ionic concentration, and thus retard precipitation.[1] On the other hand, mixtures of salts in which there is a common ion increase the ionic concentration of each and aid precipitation. For example, oxygen taken into solution by water increases the solubility of iron sulphide, since we have then not only the hydrogen and hydroxyl ions plus the undissociated water, but also the oxygen and hydrogen peroxide, according to the law that *mixed solutions of two or more salts will contain all the salts that can be made by the combination of the ions of the original salts together with the free ions.*[2] The addition of the iron sulphide to the solution adds a large number of ions to it and increases accordingly the power of the solution to take up other substances—such, for example, as limestone. By this process of addition of materials a solution becomes increasingly potent as it grows in complexity. This is true so long as the additions are such as to merely balance the ions already in solution and not to increase the ionic concentration of any one sort beyond its constant of solubility. If, however, to a solution already containing iron sulphide some other sulphide, such as zinc sulphide, be added, the increase in the amount of sulphur present may be sufficient to produce precipitation, in which case the sulphur will be thrown down probably in combination with that substance which has most nearly reached its constant of solubility and with which sulphur is capable of forming a compound.

Reactions between different materials in solution are so interrelated that it frequently happens that addition of a small amount of some substance will produce precipitation of a relatively large amount of material of a wholly different kind. This probably explains many apparently contradictory facts in the order of deposition and association of ores.

Ground water is a complex but normally weak solution. It is very dilute, and the more dilute a solution the more nearly complete is dissociation of all the materials in it. Ordinarily the weaker acids and bases, carbonic and silicic acids, are very little dissociated. As ionization is more complete in dilute solutions, carbonic and silicic acids are relatively more active in the ground water than the same amount of material in stronger solutions. It is in the action of the ground water, accordingly, that we see the greatest effects of these acids.

Precipitation.—Processes by which materials are thrown out of solution have been suggested above. In brief, a material is precipitated whenever the amount in solution exceeds its constant of solubility, or whenever the amount in solution passes the point of saturation for the particular substance. Since the amount which may be in solution is dependent upon the degree in which its ionic constituents are balanced by other materials, relatively insoluble materials may be retained in solution while more soluble materials are deposited. This balancing of one material by another in solutions and the destruction of the balance by the mingling of different solutions was probably the most powerful factor in producing precipitation in the Ozark region.

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[1] C. F. Tolman: Jour. Geol., Vol. VII, p. 591.

[2] Tolman: loc. cit., p. 590.

Decrease of heat, which normally works to produce precipitation, can not be here appealed to. There are now no warm or hot springs in the region, and there is no direct evidence that there ever have been any. The reactions involved in the work of the ground water of this region are all such as take place under ordinary and prevailing temperatures. If the factor of time be taken into account, the magnitude of the work done by the waters is not beyond that which may be properly assigned to them without appealing to increased temperature in the past.

A brief consideration of the structural features of the region under consideration will show that there is no warrant in this case for appealing to pressure to promote solution and relief from it to produce deposition. We may assume the circulating water to be practically limited below by the pre-Cambrian, since, up to the present at least, field studies have shown no reason for supposing the contrary. We may perhaps also assume that the base of the Cambro-Silurian, as developed in the Carthage deep well (1,750 feet below the surface), represents the maximum depth of those beds. These assumptions are the best which can be made, and seem warranted by the known facts of the field. If the case of water starting from the highest point in the region, Cedar Gap, be then considered, there would be a maximum depth of circulation of approximately 2,500 feet. A hydrostatic pressure of 2,500 feet is about equivalent to that of 70 atmospheres. The increase of solubility with pressure is known to differ with different substances, and has been measured in but few cases. In the case of copper sulphate, measured by Sorby, the increase at 60 atmospheres was found to be 1.91 per cent and at 100 atmospheres 3.183 per cent.[1] This increase is inconsiderable, and there are no reasons, either in the field evidence or the available experimental data, for believing that it is not representative for the class of substances here dealt with.

Decrease of heat and pressure being out of the question, the most obvious cause for precipitation is the mingling of solutions. For this there is much direct evidence, as detailed later. Mingling of solutions would occur wherever ground waters of diverse composition came together. In the readjustment following such a meeting a certain amount of precipitation is almost inevitable, though at the same time the capacity of the solvent for some other salt may be increased.

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[1] Proc. Royal Soc. London, Vol. XII, p. 538; cited by Ostwald: Solutions, p. 62.

Solution and deposition go hand in hand and are not only coordinate, but usually are contemporaneous processes. In dealing with such complex solutions as normally constitute the ground water in the presence of such numerous and diverse salts as are contained in the rocks it is obviously impossible to follow out in detail the processes of solution, transportation, and deposition. At best only the main direction of change can be pointed out and average results discussed. It is to be remembered that there is constant reaction between not only liquids and liquids, but liquids and gases, liquids and solids, gases and gases, gases and solids, and even between solids and solids. With constantly changing conditions there is an equally constant tendency to maintain equilibrium. The net result is a multitude of chemical changes, and with a wide circulation of underground waters the probability that metals important as ores may be segregated is very great.

In producing deposition the addition of one solution to another becomes important, not only because of direct action of incoming material upon the salt dissolved, but also through indirect action. Any liquid which is able to form a homogeneous whole with a solution causes precipitation if any substance in the solution is insoluble in the liquid added. An excellent example of this phenomenon is seen in the precipitation of zinc, iron, copper, and magnesium sulphates from aqueous solutions by the addition of alcohol. However, in the Ozark region probably the chief precipitating reaction was not of this kind, but was a reduction. Dilute sulphate solutions of these elements were evidently important constituents of the ground water. Organic matter is widespread, and by its reducing action the sulphates were probably reduced to sulphides and precipitated.

The order in which materials are thrown out of solution depends not only upon the degree of saturation of each, but upon a relationship known as chemical affinity, which exists between the various elements. By virtue of chemical affinity, out of a large number of reactions possible in a given case, certain ones are more apt to occur. For example, other things being equal, oxygen will combine with iron to a greater extent than with zinc and with zinc rather than lead. The several elements may be ranged in series according to their relative affinity for various substances, and the relative affinity of the various metals with reference to sulphur is of considerable importance. This has been investigated by several authors and the order, beginning with the greatest affinity as made out by E. Schürman,[1] is given below:

Pd, Hg, Ag, Cu, Bi, Cd, Sb, Sn, Pb, Zn, Ni, Co, Fe, As, Tl, Mn.

The sulphide of any one of these metals will be reduced by the sulphide of any one above it, and from a sulphide solution of equivalent saturation of each they would be thrown down in the order named. This phase of ore deposition has recently been investigated and elaborated by Messrs. Weed,[1] Emmons,[2] and Van Hise,[3] and is found to explain many puzzling features of ore deposits. It will be further discussed in connection with secondary enrichment.

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[1] Eng. and Mining Jour., Vol. L, 1890, p. 484.

Deposition according to chemical affinity is interfered with by another law known as the law of mass action, which is that chemical action is proportional to the active mass. The effect of this law is seen in the fact that iron sulphide is far more common than any of the sulphides above it in the series, even though all of the latter have a greater and in some cases a notably greater affinity for sulphur. Iron being the most common of the metals in the series, forms the largest active mass, and therefore appropriates the greatest amount of sulphur.

Diffusion.—An important influence in the action of underground water is the phenomenon called diffusion. This is the movement within a solution by which particles of a dissolved substance travel from places where they are more closely packed to where they are less in proportion until concentration is equal throughout. Cavities in the rocks below ground-water level must be conceived as filled with the ground-water solution. Whether the water be in motion or not, much transfer of material probably takes place through diffusion. In diffusion material moves through the solution rather than with it. The quantity of a given salt diffused, as well as the distance over which a determinate concentration extends, is proportional to the square root of the time during which diffusion takes place. It also varies with different substances. For example, magnesia diffuses more rapidly than zinc from a sulphate solution, so that from a solution containing both, in contact with a solution containing neither or a less quantity, the magnesia would travel a greater distance in a given time. This is probably the explanation of the fact observed in the Joplin district that dolomitization extends to greater distances from the main ore channels than does the distribution of lead and zinc sulphides. Perhaps, too, the fact that magnesium sulphate very readily forms supersaturated solutions is of importance in this connection.

Diffusion is peculiar in that colloid substances interpose no marked hindrance to the process. Materials in solution move through such a substance as freely as through water. This is probably the essential factor in the explanation of certain common phenomena in the Southwestern district. One of the most common cementing materials found in the ore breccias of that district is a black cherty material evidently deposited after the brecciation and the main deposition of the ore. It is illustrated in fig. 8, from a specimen obtained on the Boston Get-

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[1] W. H. Weed: Bull. Geol. Soc. America, Vol. XI, pp 179–206, 1900; Trans. Am. Inst. Min. Eng., Vol. XXX, p. 424.

[2] S. F. Emmons: Trans. Am. Inst. Min. Eng., Vol. XXX, p 177.

[3] C. R. Van Hise: Trans. Am. Inst. Min. Eng., Vol. XXX, p. 27.

There ground. Examination shows that the blende found in this chert has commonly a well-developed crystal outline. There is, however, no evidence of the blende having been formed in cavities. Neither are there those laminations in the matrix which usually surround crystals that have grown in soft material, and in growing have crowded the latter aside. Individual and quite perfect crystals occur wholly surrounded by the chert. Under the microscope the crystal outlines of the blende are seen to be nearly perfect, though they occasionally show embayments similar to the corrosion forms of quartz phenocrysts. These embayments are developed along cleavage planes in the blende.

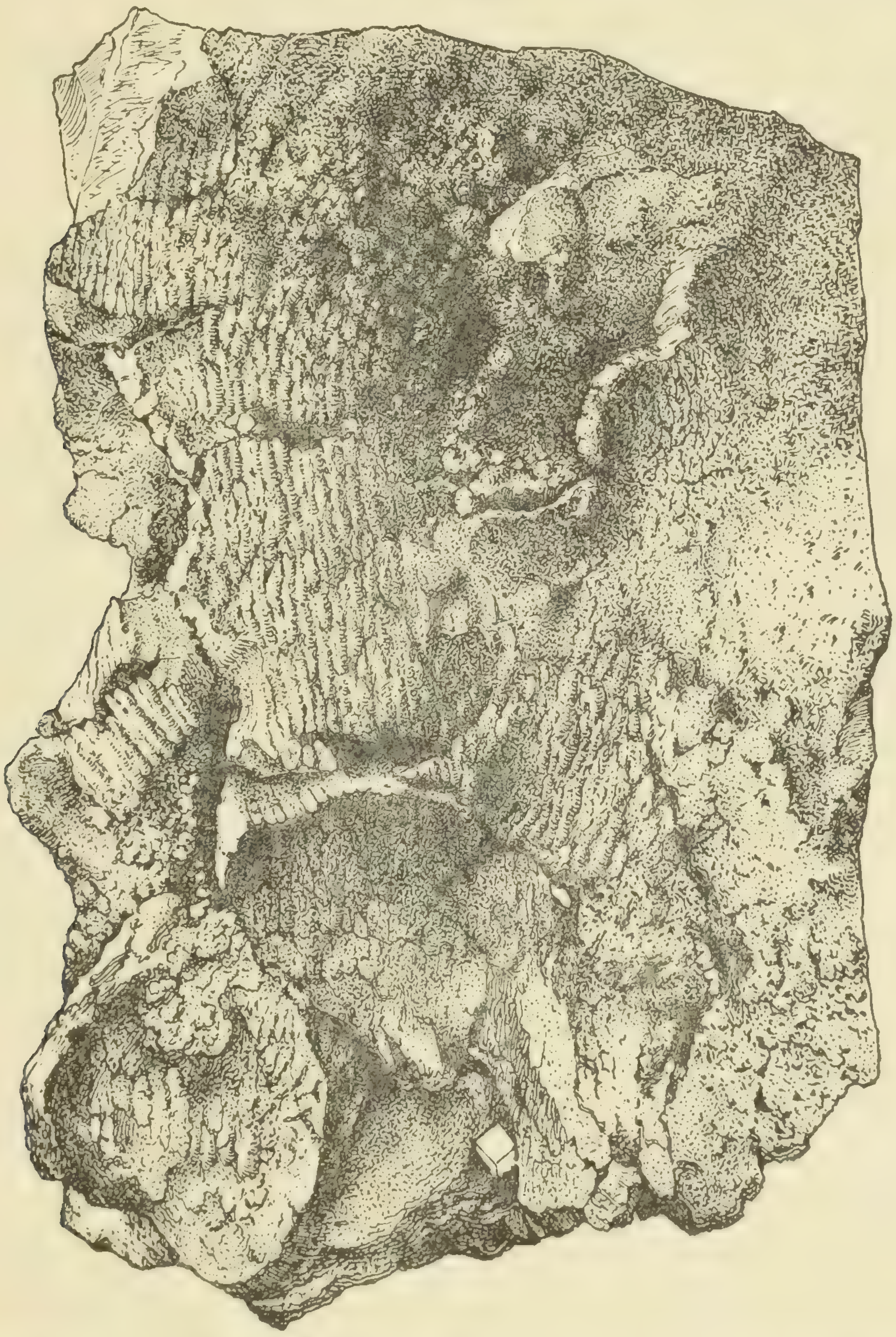

FIG. 8.—Black matrix of ore bodies after silicification, Boston Get-There mines, Prosperity, Mo.

That the siliceous material has been in soft and plastic condition is shown in fig. 8. It is suggested that at the time the blende was formed the siliceous matrix was in colloid condition, and so interposed no hindrance to the movement of the metal through it and the growth of the sulphide crystals. This suggestion is supported somewhat by the fact that in some mines the chert and the blende are so intimately mixed that they can not be entirely separated in milling. Furthermore, it has been shown by Kahlenberg and Lincoln[1] that in natural waters silica always occurs in the colloidal state. The cherts represent the main deposits of silica, and we are perhaps warranted in assuming that at the time of their formation the silica was at least largely colloidal. At present the cherts include much crystalline quartz, but E. O. Hovey[2] has shown that some of it is chalcedonic and opaline. The descriptions of the sinter deposits of the Yellowstone Park, given by Weed,[3] indicate clearly that in the case of hot springs, at least, the silica in the process of deposition goes through a colloidal state, taking eventually an amorphous or opaline form. Le Conte speaks of the silica at Sulphur Bank as being so recent as to still be gelatinous.[4] The difference in the action of hot and cold waters toward silica is one of degree only, and with the knowledge that the silica in the present case was colloidal when in solution, and now is partly amorphous and opaline, we seem warranted in assuming that it passed through a colloidal stage during deposition. Colloids have been very little studied, and the subject needs further investigation. If, however, the conditions suggested actually obtained, the later or secondary chert would be a particularly favorable habitat for the minerals, and an explanation is thus given of the common association of the two. In such material the sulphides by simple diffusion would be segregated and crystallized freely as from solution. This process of ore formation is somewhat different from both ordinary metasomatic replacement and from simple crystallization in open cavities, though it is most nearly like the latter. It is believed to have been an important process in ore deposition.

General effects of the work of underground water.—When sediments are laid down on the borders of the ocean, or in inland basins or lakes, they contain a pore space of 25 to 50 per cent,[5] and it is probable that this is true not only of the strictly mechanical sediments, such as sands and clays, but of limestones as well. Seelheim[6] has shown that clays when allowed to settle in water have a pore space of 50 to 79 per cent, and that there is no sensible reduction of this space under a pressure of 102 feet of water. Sandstones, shales, and limestones, however, as they occur at the earth's surface, have very much less pore space, the latter, even in the sandstones, being reduced to from 10 to 20 per cent.[7] It is evident that the consolidation of the sediments involves a very considerable amount of cementation, and since many of the rocks seem never to have been subjected to sufficient pressure to allow the result to be referred to dynamic agencies, an important amount of this may be due to the action of the circulation of ground water. The crystalline rocks are, as a class, notably more dense than even the cemented sedimentaries. Waters probably do not circulate through them freely, except where they have been shattered. When, however, the conditions are favorable the effect of underground waters on them may be one of cementation.

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[1] Solutions of silicates of the alkalies, by L. Kahlenberg and A. T. Lincoln: Jour. Phys. Chem., Vol. II, No. 2, 1898, p. 77.

[2] Missouri Geol. Survey, Vol. VII, 1894, p. 728.

[3] Ninth Annual Rept. U. S. Geol. Survey, pp. 613-676.

[4] Am. Jour. Sci., 3d series, Vol. XXVI, p. 9.

[5] F. H. King: Nineteenth Annual Rept. U. S. Geol. Survey, Pt. II, p. 77.

[6] Zeitschr. f. Anal Chemie, Vol. XIX; cited by King.

[7] King: loc. cit., p. 81.

Opposed to cementation is the process of weathering or disintegration. The material brought into the deeper lying rocks must be taken from the rocks which the waters have already traversed. There is accordingly above the belt of cementation a belt of weathering.[1] Both the belts of weathering and of cementation lie within the zone of fracture; that is, within that portion of the earth's crust where fractures are numerous, and the circulation of the water is active. In general, the belt of weathering is marked by depletion—loss of material—and the belt of cementation by enrichment—gain of material. There is in a large way a continuous migration downward of soluble materials as the overlying surface is eroded. The belt of weathering lies mainly above water level, and the belt of cementation below it. It is to be remembered, though, that weathering and cementation are processes that retain their characteristics at whatever depth they take place. It is in a broad way only that one is confined to the upper and superficial portion of the strata, and the other to the lower and deeper strata.

Weathering is marked as a rule by oxidation, carbonation, hydration, and solution. The mechanical results are disintegration, softening, and the decomposition of rocks. In the belt of cementation, oxidation and carbonation are less active. Hydration occurs very extensively. Instead of solution deposition is normally taking place. The result is a filling of cracks and crevices and a general cementation of the rock. The "hard ground" ore bodies found in many of the Joplin mines is typical of deposition in the belt of cementation. Such may be later softened and disintegrated by being overtaken by the downward march of the belt of weathering as a result of surface erosion. Excellent examples of this may be seen in the soft ground in the Missouri Zinc Fields mines at Webb City.

While solution is normally most active in the belt of weathering and above the water level, it also occurs below, and in exceptional cases its results are very important. The Joplin region affords some most striking instances of this phenomenon. One of the best examples is at the Crystal Cave, in the western part of Joplin, owned by Mr. James Roach. This is from 10 to 25 feet high, 20 to 40 feet wide, and approximately 225 feet long. It lies below the normal ground-water level, and was discovered only after that level had been lowered by pumping. The cave is entirely lined with crystals of calcite of predominant scalenohedral form and of unusual size. Single crystals 22 inches long are found. The cave is in truth an immense geode. Such caves are not uncommon in the region, though this is the largest one examined. The Nickel Plate or Sphalerite mine at Aurora includes such a cave. In the Diamond Jack mine, in Chitwood Hollow, a similar cave was broken into. Smaller caves, running down to mere druses and channels a few inches across, are widespread and show that the phenomenon is not due to any local cause.

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[1] Van Hise: Sixteenth Ann. Rept. U. S. Geol. Survey, Pt. I, p. 581; Jour. Geol., Vol. VIII, pp. 749-752.

In general, large underground caves are formed only where the rocks stand high above the controlling water level, and where there is as a result a free circulation downward. In this region there is no evidence that such conditions ever obtained, and we must conclude that in broken and soluble rocks solution may become so important below water level as to produce openings of considerable extent. In none of the caves examined were there any stalactites or incrustations of lime, such as are so closely associated with caves formed above water level. Instead, the walls are uniformly lined with crystals, which in the caves, especially in the Roach cave, are of great size. Crystals do not grow out of solutions except under peculiar circumstances. Salt crystals may be formed in a damp atmosphere, but it is impossible to suppose that crystals of calcite so large and perfect as those that occur here were formed except under water. They required the maximum favorable conditions for their production, and these conditions are realized only in the presence of an abundance of material in a medium through which it moves freely—that is, in a saturated solution. It is also significant that where slabs of the crystal lining are broken off or have fallen off the wall rock is found to be fresh, hard, and unoxidized. In the case of the Roach cave, ores presenting all the evidence of original concentration occur in the rock above the cave. If the latter be supposed to have been formed above water level, it is necessary to believe that at the time it was being formed the rocks above were likewise in the belt of weathering. They show, however, no evidence of oxidation or other weathering agencies, though they carry sulphides which normally yield very readily to such agencies.

An interesting phenomenon of the Joplin caves is the fact that in them the weight of the roof is occasionally partly supported by the hydrostatic pressure of the water. When the water is pumped out the roof may fall in. This occurred at the Budweiser mine at Tuckahoe. Near the Sand Ridge mine, at Aurora, great cracks similar in appearance to those formed by earthquakes developed in the summer of 1900 as pumping lowered the ground-water level. Near Carl Junction a section of railway track at one time sank, presumably as the result of pumping, in this instance some distance away.

CHAPTER V.

By H. F. Bain.

MINERALS AND ORES.

MINERALS.

In the Ozark region a notable variety of minerals is found. In general all are widely distributed and the mineralogical differences between the various subdistricts grow out of the relative abundance of the different minerals. But to some extent the association in the various subdistricts is different and certain species occur at particular points only. For example, nickel and cobalt, which in small quantities characterize the sulphides of the Southeastern district, are not known to occur elsewhere in this region, and fluorite and topaz occur only in connection with the ores at the Einstein mine.

A practically complete catalogue of the minerals of the Southwestern district has been published by Mr. A. F. Rogers, of the University Geological Survey of Kansas.[1] He lists in all forty-four species. Those of the minerals which especially characterize the ores and are significant either because of their abundance or the light which they throw on the genesis of the ores are given below.

Minerals of the Southwestern district.

Name.	Composition.	Probable constitution.
Sphalerite (blende)	ZnS	ZnS.
Calamine	$H_2Zn_2SiO_5$	$2ZnOH_2OSiO_2$.
Smithsonite	$ZnCO_3$	$ZnCO_3$.
Hydrozincite		$ZnCO_32Zn(OH)_2$.
Goslarite	$H_{14}ZnSO_{11}$	$ZnSO_4+7H_2O$.
Galena	PbS	PbS.
Cerussite	$PbCO_3$	$PbCO_3$.
Anglesite	$PbSO_4$	$PbSO_4$.
Pyromorphite		$(PbCl)Pb_4Pb_3O_{12}$.
Leadhillite		$4PbOSO_32CO_2H_2O$.

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[1] Kansas University Quarterly (A), IX, No. 2, pp. 161-165.

Minerals of the Southwestern district—Continued.

Name.	Composition.	Probable constitution.
Marcasite	FeS_2	FeS_2.
Pyrite	FeS_2	FeS_2.
Hematite	Fe_2O_3	Fe_2O_3.
Limonite	$H_6Fe_4O_9$	$2Fe_2O_3+3H_2O$.
Melanterite	$H_{14}Fe_2SO_{11}$	$Fe_2SO_4+7H_2O$.
Copiapite		$2Fe_2O_35SO_318H_2O$.
Chalcopyrite	$CuFeS_2$	$CuFeS_2$.
Malachite	$H_4Cu_2CO_5$	$CuCO_3Cu(OH)_2$.
Azurite	$H_4Cu_3CO_5$	$2CuCO_3Cu(OH)_2$.
Cuprite	Cu_2O	Cu_2O.
Covellite	CuS	CuS.
Chrysocolla		$CuSio_3+2H_2O$.
Aurichalcite		$2(ZnCu)CO_33(ZnCu)(OH)_2$.
Caledonite		$(PbCu)SO_4(PbCu)(OH)_2$.
Linarite		$(PbCu)SO_4(PbCu)(OH)_2$.
Greenockite	CdS	CdS.
Barite	$BaSO_4$	$BaSO_4$.
Gypsum	H_4CaSO_6	$CaSO_42H_2O$.
Calcite	$CaCO_3$	$CaCO_3$.
Dolomite	$CaMgC_2O_6$	$CaCO_3MgCO_3$.
Quartz	SiO_2	Completely crystalline silica.
Chert	SiO_2	Partly crystalline silica.
Pyrolusite	MnO_2	MnO_2.
Sulphur	S	S.
Bitumen		A group of organic compounds of considerable variety in composition.

It will be seen that these minerals include a number of simple and mixed metallic sulphides, their alteration products—the sulphates, carbonates, and silicates—the original silica and nonmetallic carbonates, certain of the by-products of the reactions incident to the alteration of the original minerals, and the bitumen which, in many cases at least, furnished the reducing agents.

The Central district is not marked by any minerals not found in the other districts, but shows a greater abundance of barite than is common in the Southwestern and North Arkansas districts. In the association of the ores found it is closely related to the Southeastern district.

In the latter there are, in connection with the granites, a number of additional minerals. These are mainly of petrographic interest. In connection with the sulphides of lead and iron in that region minor quantities of nickel and cobalt occur. These elements show as siegenite ($(NiCo)_3S_4$), smaltite ($CoAs_2$), and asbolith, a variable mixture of cobalt, iron, and copper oxides. At the Einstein mine, which is within the Southeastern district, there is a very distinct association of minerals, including argentiferous galena, fluorite (CaF_2), wolframite $(FeMn)WO_4$, zircon ($ZrSiO_4$), and topaz ($Al(OF_2)\ AlSiO_4$).[1]

In southwestern Arkansas antimony compounds become important, and stibnite (Sb_2S_3), jamesonite ($Pb_2Sb_2S_5$), stibiconite ($H_2Sb_2O_5$), bindheimite, a hydrous antimony lead oxide, zinkenite ($PbSb_2S_4$), and related forms are found.

Certain of the useful minerals are sufficiently abundant in each district to make it profitable to mine and market them. These accordingly constitute ores. Certain others either do not occur in sufficient abundance or are of too low value to be worthy of development. These will be here spoken of as associated minerals. Still others of no value to man, and certain mixtures of minerals, such as impure limestone, occur in close association with the valuable minerals and in such abundance as to constitute the mass or matrix surrounding the ore proper. These minerals will be spoken of as gangue minerals.

ORES.

Within the entire region the minerals which are of chief economic importance are the zinc ores, the lead ores, the iron ores, the manganese ores, the barite, and the subordinate amounts of antimony, silver, and copper which are occasionally marketed. The present paper is concerned especially with the zinc and lead ores, and minerals other than those of lead and zinc will not be considered except as they are associated with these.

LEAD ORES.

Galena.—This mineral is the most important one of the lead series. It is now the only one of the lead minerals in the region which has any considerable economic importance. Galena is widely distributed, occurring in all the districts. It occurs both as well crystallized individuals showing cubic and octahedral forms and as disseminated crystalline aggregations.

Pure galena is a lead-gray color, is opaque, and has a bright metallic luster, especially on cleavage faces. The cleavage is perfect parallel to the cubic faces and less perfect parallel to those of the octahedron. The specific gravity is 7.4 to 7.6, hardness 2.5 to 2.75. Pure galena is composed of 86.6 per cent of lead and 13.4 per cent of sulphur. The percentage of lead in the ore as commonly dressed is about 80. As sold the galena usually carries a greater or less amount of pyrite, limestone, and chert, which are the chief impurities. Galena melts at a red heat, and is volatilized at a bright red heat in the presence of air. It is in other regions associated with variable amounts of silver, zinc, copper, antimony, bismuth, cadmium, and other metals. The association with silver is exceptionally close. The galena found in the Ozark region is unusually free from those impurities, and is known commercially as nonargentiferous or soft lead. It carries minor amounts of silver,[1] but only at the Einstein mine and in southwestern Arkansas, beyond the strict limits of the Ozark region, does the silver become commercially important.

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[1] E. Haworth: Am. Geologist, Vol. I, p. 295.

Cerussite.—The carbonate of lead is known locally as dry bone or wool mineral. Dry bone is a term applied elsewhere and to some extent in this region to zinc carbonate, but in the Southwestern district it more frequently refers to lead carbonate. The latter is clearly a superficial alteration product from the galena. In former years, when the shallow deposits only were worked, it formed a considerable part of the production, but now it is rarely found in quantity. Pure cerussite carries 77.5 per cent of lead, corresponding to 83.5 per cent of lead oxide, which is combined with 16.5 per cent of carbon dioxide. It is normally mixed with impurities which alter its appearance and form. Its usual occurrence in the region is as a dingy-white coating over crystals of galena, but it is also granular and not infrequently crystallized.

ZINC ORES.

Sphalerite (blende or jack) is the simple zinc sulphide, composed of 67 per cent of zinc and 33 per cent of sulphur. Blende as marketed in the Southwestern district carries normally from 50 to 65 per cent of metallic zinc. Prices are made on a 60 per cent basis. Except where iron is unusually abundant the blende when well cleaned should run about 62 per cent. A smaller percentage in most cases is due to imperfect separation of the ore from the chert and limestone. An ore grading above 62 per cent commands a premium in price. Blende occurs in various forms of the tetartohedral division of the isometric system, and often shows slightly rounded faces. It is transparent to translucent, and varies in color from a light rosin yellow to a deep ruby red, a steel blue, or a jet black. It has a very perfect rhombic dodecahedral cleavage, and by a little care the whole twelve faces may be cleaved out of a single piece. The hardness is 3.5 to 4, and the specific gravity is 3.9 to 4.1. Blende usually contains a variable amount of iron and minor amounts of manganese, lead, copper, and cadmium. It occurs as isolated but usually distorted crystals, and as crystalline masses in cavities, and serves as a matrix in breccias. An amorphous white powdery form has been found in limited quantities at Galena, Kans.

Calamine (zinc silicate) is a hydrous mineral, including silica 25 per cent, water 7.5 per cent, and zinc oxide 67.5 per cent, corresponding to 54.2 per cent metallic zinc. Silicate as marketed usually carries from 40 to 50 per cent of metallic zinc. The chief impurities are gangue materials, particularly clay, chert, and limestone. Calamine is transparent to translucent, has a vitreous luster, and is colorless, clear white, and yellowish to brown. It occurs in mamillary and botryoidal forms, and also as bunches of thin tabular crystals. The hardness is 4.5 to 5 and the specific gravity 3.4 to 3.5. It may be recognized by its tendency to gelatinize with acids, by which it can be distinguished from the carbonates of zinc, which effervesce. It is commonly associated with clay, and the so-called tallow clays as a result often contain important amounts of zinc. Calamine occurs as an alteration product from sphalerite, and specimens from Aurora, Mo., show the entire process of the change. It is an especially characteristic alteration product in the Southwestern, but is rarer in the other districts.

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[1] Winslow: Missouri Geol. Survey, Vol. VII, 1894, p. 455.

Smithsonite is the anhydrous zinc carbonate, while hydrozincite is the corresponding hydrous form. The former contains 64.8 per cent of zinc oxide, corresponding to 52.03 per cent of metallic zinc, while the latter carries 75.3 per cent of the oxide and 60.47 per cent of the metal. Much more carbonate than hydrozincite reaches the market. The two minerals are particularly closely related to limestone, and much of the carbonate marketed is, in fact, limestone impregnated with zinc. In this form, as "rock bone" and the weathered "clay bone," it may carry as little as 25 to 30 per cent of zinc and still find sale. The better grades of rock bone run 40 to 45 per cent. The clear stalactitic varieties run from 40 to 50 per cent in zinc and are much preferred by oxide burners. Both smithsonite and hydrozincite are soluble in hydrochloric acid, with effervescence, and both occur in earthy form, as mamillary and stalactitic incrustations, and in pseudomorphs after blende and other earlier formed minerals. There is a slight difference in hardness and in pecific gravity, the former being 5 for smithsonite and 2 to 2.5 for hydrozincite and the latter 4.30 to 4.45 and 3.58 to 3.8, respectively.

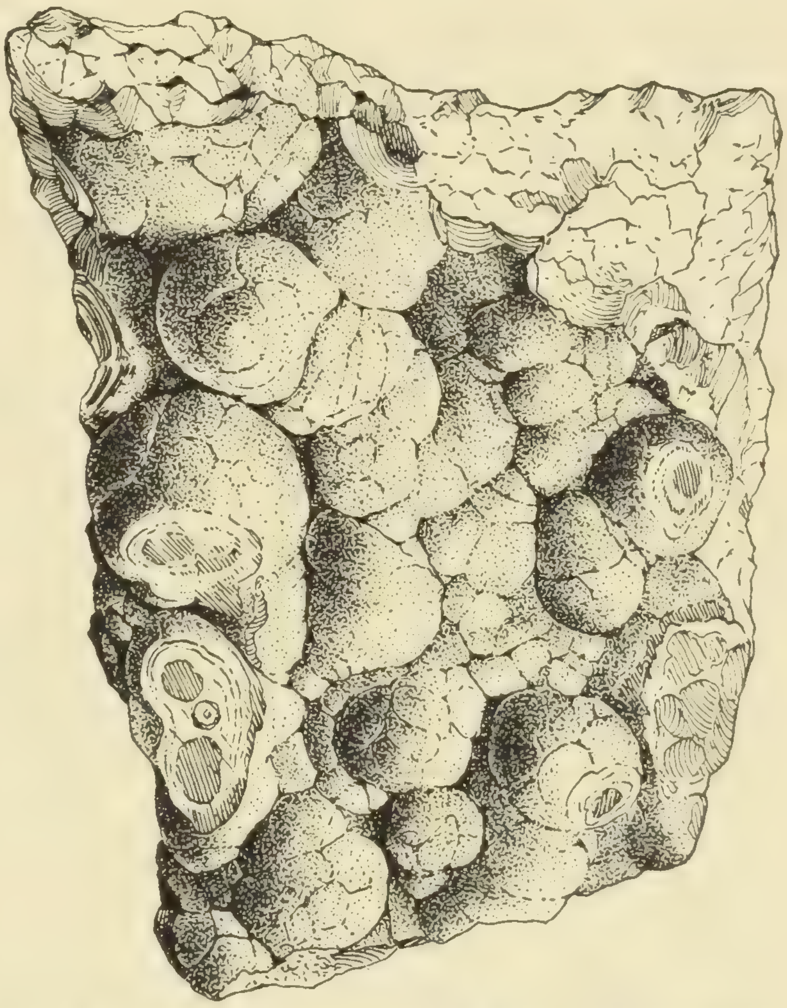

FIG. 9.—Mamillary smithsonite from Morning Star mine, Rush, Ark.

The carbonates of zinc assume a wide variety of forms and color, and to some of these special forms local names are given. The variety known as "turkey fat" is usually a brilliant yellow anhydrous carbonate, though the term is also occasionally applied to the silicate. The carbonates occur in the greatest variety, abundance, and beauty in the North Arkansas district.

USES OF THE ORES.

The galena finds a ready sale for simple and direct reduction to lead. In certain cases it is in demand among smelters as a flux for rebellious argentiferous and auriferous ores. For such purpose it occasionally sells at a slight premium. The blende is sold entirely to manufacturers of spelter, as pig zinc is called. The carbonate and silicate of zinc are sold mainly to be burned to oxide, oxide of zinc or zinc white being a valuable base for paints. It serves the same purpose and is used as a substitute for white lead. Considerable quantities of the silicate are purchased by spelter manufacturers. It is said that a retort mixture of equal parts of calcined silicate and roasted blende make a spelter which rolls to an especially pliable and, for certain purposes, valuable sheet metal.

ASSOCIATED MINERALS.

The most important minerals associated with the zinc and lead ores are calcite, dolomite, the iron sulphides pyrite and marcasite, chalcopyrite, and barite.

Calcite in its broader sense makes up the bulk of the Carboniferous limestones, which are nonmagnesian, and forms an important part of the Siluro-Cambrian magnesian limestones. As a crystallized mineral it occurs in wide variety and great beauty of form, particularly in the Southwestern district. It is known to the miners of the region as "tiff," and the sharp scalenohedral forms are spoken of as "points." The crystallography of the Joplin calcites has recently been studied by Farrington.[1]

Dolomite occurs in intimate association with the ores of the entire region. It is in three forms: first, the massive dolomite or dolomitic limestone, which forms the country rock in the entire Cambro-Silurian area; second, the so-called gray spar of the Joplin region; and, third, the pink spar, which is prominent in the Southwestern and North Arkansas districts and occurs less abundantly in the Central and Southeastern districts. The gray spar is made up of small rhombohedrons of dolomite, associated with calcite and unaltered normal nonmagnesian limestone. It occurs in intimate association with the ores of the Southwestern district, and marks apparently a metasomatic development of dolomite from the normal Carboniferous limestones around the ore bodies. The pink spar is a normal crystallized dolomite, occurring with sharply curved rhombohedral faces. The bright pink color is probably due to a slight admixture of manganese carbonate. The pink dolomite is usually very fresh and but little altered, so that it affords very beautiful cabinet specimens.

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[1] O. C. Farrington: Publication Field Columbian Museum No. 44.

The iron sulphides are relatively abundant in all of the districts, and yet as compared with mining regions elsewhere they are unusually rare. The great bulk of the iron of the Ozarks occurs in the form of oxides, the Iron Mountain and Pilot Knob deposits being the best-known occurrences. Aside from them, however, there are a large number of smaller iron deposits scattered throughout Missouri[1] and Arkansas.[2]

The segregated iron here, as elsewhere, forms a relatively small portion of the total iron in the district, since all the rocks of the entire region contain at least small quantities of iron, probably existing in most cases as either oxides or carbonates. In view of the wide distribution of the iron, it would seem that the law of mass action would require the development here, as elsewhere, of a quantity of iron sulphide far in excess of that of zinc and lead. As a matter of fact, however, the iron sulphides, while widely distributed and frequently distressingly abundant in individual mines, are notably deficient in quantity in the region as a whole. It is not improbable, for reasons later discussed, that deeper workings will show the iron sulphides in greater quantity, but in view of the wide and abundant presence of the iron it can only be assumed that either the amount of sulphur present was deficient, a fact of which we have little direct evidence, or that the phenomena are due to a cause or causes to which we have as yet no clue. If there was a lack of sulphur, the lead and zinc would, of course, rob the iron, and hence force the latter to remain in carbonate form; but of this we have no independent evidence, except in the occurrence of secondary siderite in the Boston Get-There mines.

Both pyrite and marcasite are widely distributed, though the latter is much the more common form. Both occur massive and crystallized, the marcasite probably being more frequently in crystal form than the pyrite. The marcasite shows bunches and groups of flat tabular crystals. The pyrite, as usual, shows various faces of the cube and pyritohedron.

Chalcopyrite is widely distributed and is especially abundant in the Joplin region. It may be distinguished from the simple iron sulphides by a tendency to show copper stains on weathering and by the ease with which it may be scratched with a knife. It occurs in beautiful sphenoids sprinkled over all the ores and minerals (fig. 10), and is undoubtedly the source of the various copper compounds found in the district. A peculiarity of the chalcopyrite is a frequent tendency of the individuals to grow with a common orientation over the surface of the other minerals—a cluster of blende crystals, for example.

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[1] Report on iron ores, by F. L. Nason: Missouri Geol. Survey, Vol. II, 1892.

[2] Penrose: Rept. Arkansas Geol. Survey for 1892, Vol. I, 1892.

Barite, known as heavy spar in the Southwestern district, and elsewhere as tiff, is abundant in the Central and Southeastern districts, where it occurs massive, crystallized, and as pseudomorphs, but is rare elsewhere. Forms collected in Tanyard Hollow, southwest of Joplin, show the usual flat tabular crystals, developed parallel to the basal pinacoid and bounded by the prism. The occurrence of greenockite is of interest because of its rarity elsewhere. It occurs widely distributed throughout this region in connection with the zinc blende, and occasionally is relatively abundant. On the Boston Get-There ground, at Prosperity, Mo., it is common, occurring as a greenish-yellow powder dusted over the blende, chalcopyrite, marcasite, galena, and siliceous matrix.

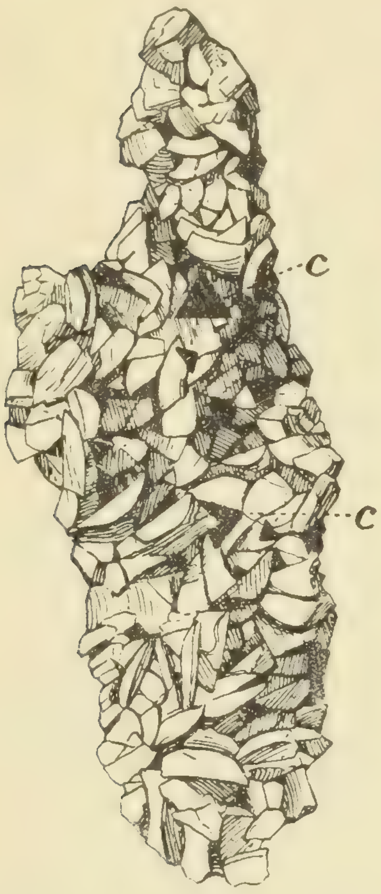

FIG. 10.—Chalcopyrite on dolomite, Estrada mine, Joplin, Mo. *c c* crystals of chalcopyrite.

Bitumen is very commonly associated with the ores in the Southwestern district. It is known to the miners as coal tar and is a black, sticky compound which, when touched with a candle or match, burns with sputtering and scintillation of sparks. It is found in druses and cavities and oozes out of the rocks in freshly fractured surfaces. In certain mines, the Glendale at Joplin among others, it drips down from the walls and the roof and accumulates in puddles. In the Kingfisher mine, in Chitwood Hollow, it is so abundant as to frequently clog the rolls in the mill. At this mine the crushed ore, with fragments of white chert set in the bituminous matrix, reminds one strongly of the mastic used in asphalt paving. Bitumen shows more abundantly in those ores which are developed in the limestone or are closely associated with the limestone and is relatively rare in the chert. When it appears in the latter it is usually in such situations as suggest that it has been brought in from some other rocks. In the magnesian and dolomitic limestones of the Cambro-Silurian it is not known to occur.

At the Sand Ridge or Bowyer mine at Aurora an impure allophane occurs in the upper levels. A partial analysis by George Steiger, made in the Survey laboratory, shows, in addition to small amounts of CaO and MgO, the following composition:

Analysis of allophane from Sand Ridge or Bowyer mine, Aurora, Mo.

Constituent.	Per cent.	Constituent.	Per cent.
SiO_2	23.48	H_2O above 100°	17.74
Al_2O_3	32.94	P_2O_5	1.30
H_2O below 100°	19.48	Sp. gr., 1.9.	

GANGUE MINERALS.

Each of the minerals associated with the ores when occurring in quantity may serve as the gangue or matrix of the ores. There are certain of them, however, which more commonly assume this rôle. In central Missouri and in Franklin and Washington counties of southeastern Missouri, barite is a very common gangue. In the Merrimac mine at St. Clair, Mo., the fissure is in places entirely filled with white barite, through which crystals and crystalline masses of galena and blende are scattered (see fig. 11). This is true also at the Lost Hill mine, in the same neighborhood, and, according as the galena, blende, or barite is the most abundant at a particular point, it serves as the gangue or matrix for the other minerals.

Quartz is an unusual gangue mineral throughout the immediate region studied, but a common one in southwestern Arkansas, where it occurs in clear white massive form, serving as a matrix for blende, galena, chalcopyrite, and stibnite. It is also present in comby form as one of a series of minerals developing the typical ribbon structure and the phenomenon defined by Posepny as crustification.[1] This is especially well shown in the Bellah mine near Gillham. In the Joplin region quartz occurs very rarely and when present shows in druses only, as in certain specimens from the Boston Get-There ground.

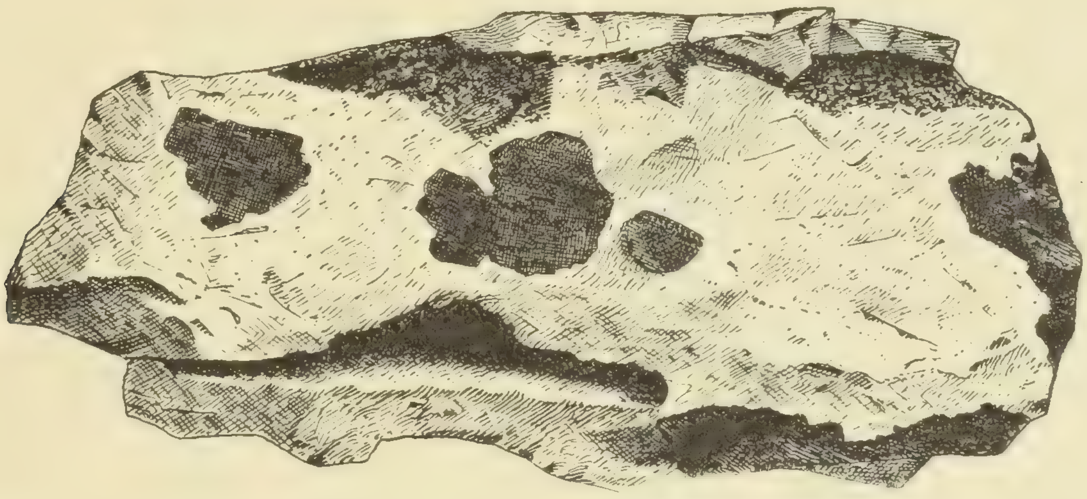

FIG. 11.—Galena with barite serving as gangue, Merrimac mine, St. Clair, Mo.

Dolomite is the commonest gangue mineral throughout the entire region. In the Carboniferous limestones of the Joplin district there is a very intimate association between the ores and the process of dolomitization of the country rock. This dolomitization is clearly secondary so far as the recrystallization of the country rock is concerned, though it in part antedates the ores and is not known except in the ore regions. In central and southeastern Missouri dolomitic sands, resulting from the decomposition of the country rock, are commonly associated with the ores in the upper altered portion of the ore bodies, but crystals of dolomite are rare. This association is strikingly like that of the ores and country rock in the Wisconsin-Iowa region. It is the more peculiar in that the country rock necessarily makes large quantities of dolomite available to the circulating waters, and is evidently an indication of the fact that the conditions there are favorable to solution but not to deposition of dolomite. In northern Arkansas, where magnesian and dolomitic rocks also form the country rock, crystallized dolomite is as common a gangue as in the Joplin region. The dolomite occurs as a pink, crystalline, and crystallized matrix which, with the brown blende and the bright blue of the pieces of country rock in the breccias, forms a very beautiful combination of colors. The blue dolomitic rock fades rapidly on exposure and the pink in time loses some of its vividness. This sort of ore is particularly well shown at the Casper and other mines in the vicinity of Smithville, in Lawrence County. At the Rush Creek mines, in Marion County, Arkansas, the pink crystals of dolomite are also very common in the ore bodies.

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[1] F. Posepny: Trans. Am. Inst. Min. Eng., Vol. XXIII, p. 207.

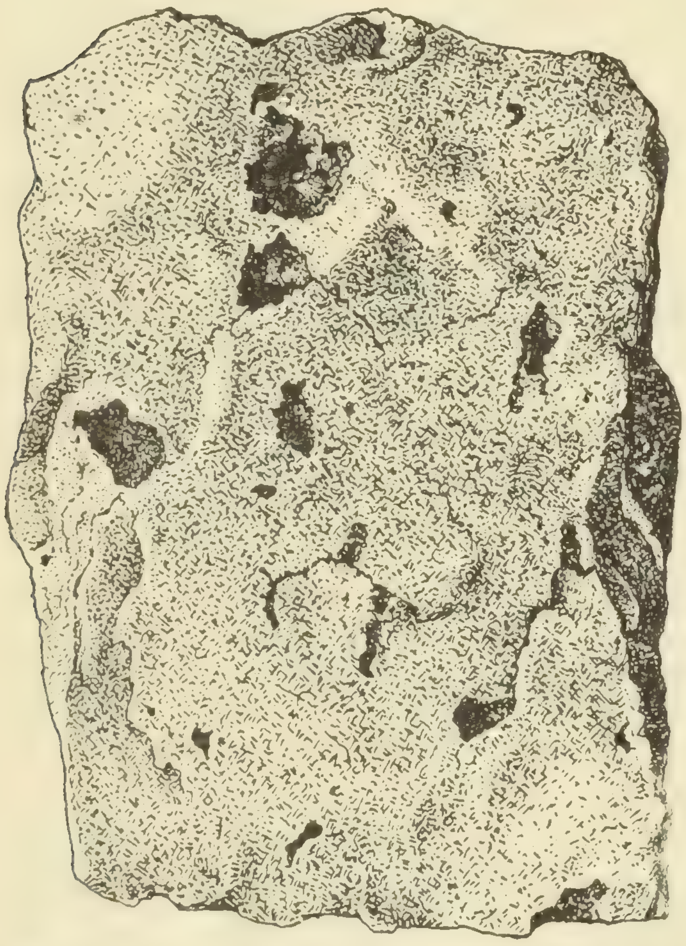

FIG. 12.—Characteristic dolomite showing rough surface and small druses, Potosi, Mo.

The two sorts of dolomite are excellently shown in a specimen from the Red Cloud mine on Rush Creek. Macroscopically the specimen shows interbanded pink and gray dolomite. The bands of pink dolomite are horizontal, and from a few millimeters to a half-inch in thickness. The gray dolomite bands are thicker, the pink being clearly subordinate. Under the microscope the gray rock shows as a granular mass of crystalline dolomite and quartz. The crystal outlines are very irregular, and the dolomite includes considerable coloring matter, probably largely ferrite. The grains are from 0.30 mm. to 0.60 mm. in diameter. Blende is plentifully developed in small irregular crystalline masses. The pink dolomite mass shows much larger crystals of dolomite, ranging up to 2 mm. in longer diameter, no quartz, and very much less pigment. No blende is developed in this portion of the slide, though other specimens show crystals of blende with the dolomite. The gray spar or dolomite represents apparently a partial metasomatic replacement of the original limestone country rock. The pink spar has crystallized freely in open space. It fills cavities produced by later stresses by which the rock has been sheeted.

Calcite, both crystalline and in the form of more or less impure recrystallized limestone, is a common gangue mineral throughout the entire region. The crystallized calcite fills seams and cracks, lines druses and water channels, and even great caves. It occasionally makes up the entire matrix of the breccias. In such a case it is full of impurities, and the resulting material has the appearance of ordinary recrystallized limestone. Some of this is so impregnated with bituminous matter as to be properly a bituminous limestone.

The most important gangue material, especially in the breccias, is chert. This occurs in the region in two forms, which are easily distinguished in the field and which have very different relations to the ores. The two sorts of chert are spoken of in this report as older and later chert. The latter is also referred to as secondary chert. It is not to be thought of as secondary in the sense of being an alteration product due to the action of waters connected with the general processes of superficial alteration. It is merely secondary or later as compared with the common chert of the country rock and with the main period of deposition of the metallic sulphides. As a rule, the earlier chert may be distinguished from the later by the color, the former being white or bluish, and the latter black. The dark color of the later chert seems due mainly to organic matter and subordinately to iron. The older chert occurs widespread in the country rock and has no direct relation to the ores except as fragments of it and other sorts of country rock occur in the ore-bearing breccia. The secondary or later chert is a very common gangue material, often serving as a matrix for the breccias. Macroscopically it may be distinguished from the older chert not only by the darker color, but frequently by a partially granular texture and the large amount of impurities which it carries. In fact, it grades over into secondary limestone or even dolomite, the name applied depending upon the degree of silicification. A specimen of the later chert from Oronogo was analyzed by George Steiger in the Survey laboratory. The results are shown below in Analysis I:

Analyses of chert.

Constituent.	I.	II.[a]	III.[b]	IV.[b]
SiO_2	95.26	95.77	97.33	94.72
Al_2O_3	.57	1.84	1.89	4.00
Fe_2O_3	None.			
FeO	.69			
MnO	None.	....	....	....
MgO	.05	.24	.09	Trace.
CaO	.25	.54	.11	1.18
Water	....	1.17	.77	....
Organic matter	Large.	....	....	....

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[a] Analysis by L. G. Eakins, U. S. Geol. Survey.

[b] Analysis by St. Louis Sampling and Testing Works. Analyses II, III, IV, from Jenney: op. cit., p. 26.

Under the microscope there is a very great difference in the appearance of the two sorts of chert. The older chert, as exhibited in a specimen from Central City, Mo., shows a mottled surface of irregular areas of quartz. These range in size from 0.02 mm. in diameter down to cryptocrystalline. They are exceedingly irregular and grade into each other on all sides. Among them are roundish to subangular areas of nonpolarizing material 0.05 to 0.15 mm. in diameter, showing for the most part no color in ordinary light. In a specimen from the Missouri zinc fields they are more conspicuous, and the pigment in them shows a zonal arrangement. Possibly they represent fossils, and are composed of amorphous silica. Hovey,[1] reports chalcedony in certain of these cherts, as shown by microscopic observations and by the solubility of a portion of the chert in caustic potash. None was recognized in the sections examined. The older chert carries no blende.

The later or secondary chert shows under the microscope a very different aspect. The rock is made up of rectangular quartz areas from 0.02 to 0.06 mm. in diameter, with the longer diameter two to three times the length of the shorter. These blades of quartz are in a groundmass of finer quartz showing all variations in coarseness down to cryptocrystalline. The coarse quartz blades have a generally random arrangement which is suggestive of ophitic structure. Occasionally there is a tendency toward an arrangement with the longer diameters at right angles, which gives an impression of a graphic granite. No amorphous silica was distinguished in the slides examined, though it may be present. In general the quartz in the later chert is much coarser grained than in the earlier. The later chert also carries much more impurity. Blende in particular is found commonly in this chert.

Much of the blende mined in the Southwestern district occurs in small crystals and crystalline masses scattered through this chert. Under the microscope the blende shows a well-developed cleavage, and its characteristic color in reflected light. The blende never occurs in the older chert. In the younger it commonly has its own crystal form. It may show forms analogous to the common corrosion forms of quartz, though these are developed along cleavage planes in the blende. In one case observed the blende maintained its own form at contacts with the older chert, and a very small crystal of blende was found within the latter near the contact. This is, however, very uncommon.

The later or secondary chert is the most common gangue in the Southwestern district. It may fill the entire space between the fragments of original rock and itself be full of crystals of ore, or it may run off in seams, filling cracks in the other materials of the ore body.

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[1] Missouri Geol. Survey, Vol. VII, 1894, pp. 727-739.

It may either partially replace the various other materials or may form over them. It is common to find pieces showing on the under side impressions of dolomite crystals, of blende, and of galena, indicating that the chert formed over them and that they were later leached out. Such specimens were collected at the J. F. Wilson mine, southwest of Joplin, at Galena, and elsewhere.

Clay is a very common gangue. This is either the red clay of the upper openings or the more widely distributed black clay known to the miners as selvage. The red clay is residual material resulting from decay of the rocks, especially limestones. It is strictly a surface phenomenon, except where developed along cracks reaching down into underlying rocks, or where entrained by downward-flowing water. Its presence is indubitable evidence of oxidizing agencies. The black clay results from the decay of the bituminous limestones in a reducing medium and from the breaking down of the Coal Measures shales. It represents in part normal clay partings in bedded limestones left behind when the more soluble portions of the limestone were carried off in solution, and in part material from the overlying shales mechanically carried into the ore bodies. The former source has probably more importance than has heretofore been assigned to it. This black clay gives color to and makes up part of the bulk of the secondary limestones and cherts which so commonly act as a matrix.

ASSOCIATION OF THE ORES.

The association of the ores by commercial districts has already been suggested. Blende with calamine and galena are the more important ores of the Southwestern district. Galena with a smaller amount of blende is marketed from the Central district. Galena is much the most important ore of the Southeastern district, though minor amounts of zinc ores, principally carbonates, are marketed from Washington and Franklin counties, and these two counties form one of the few important sources of barite in the United States. The North Arkansas district shows relatively little galena and an exceptional development of the carbonate of zinc, including hydrozincite, which elsewhere is rare. Blende is also coming into the market from this region.

The differences between the geological districts are much more strongly marked. The Carboniferous limestones contain relatively more zinc than the Siluro-Cambrian, and less lead. The blende in the Carboniferous limestone commonly alters to calamine, the silicate, while in the Siluro-Cambrian it changes to the carbonate. This is so true that the reverse occurrence is wholly exceptional. The Siluro-Cambrian deposits are associated with very much greater quantities of barite, which, indeed, is rare in the Carboniferous. They also carry minor amounts of a number of minerals commonly associated with ore deposits elsewhere, which are either entirely absent or occur only in the smallest quantity in the Carboniferous deposits.

CHAPTER VI.

By H. F. Bain.

THE ORE BODIES.

THE COUNTRY ROCK, AND ITS INFLUENCE ON THE SHAPE OF ORE DEPOSITS.

If the entire region be taken into account, it may be said that the ore bodies are inclosed in a wide variety of rocks. Every formation in the region contains ore bodies, and every variety of rock, from the pre-Cambrian granites to the Coal Measures shales, at some point serves as country rock. Yet certain formations, and within these formations certain kinds of rock, afford especially favorable conditions for the deposition of ore, so that they are of major importance in the study of ore bodies.

The granites, to a limited extent, form the country rock in the Southeastern district. Except at the Einstein mine they do not seem to be connected with any unusual characteristics of the ore bodies either in form or in association of the ores. At Doe Run a considerable amount of ore has been taken from pre-Cambrian valleys cut in the granite and filled with Cambrian sandstones and limestones.[1] Well-rounded bowlders of granite were taken from these basal beds and may now be seen in the office of the Doe Run Company. At Mine La Motte a somewhat similar ancient irregular surface of the granite was to be seen in the mine workings in 1898. At the Einstein mine in Madison County, Mo., the vein occurs in the common pre-Cambrian granite of the district. This mine has been described by Haworth,[2] Winslow,[3] and Keyes.[4] The granite is a normal coarse-grained, red biotite-granite or granitite. The mine is on a well-defined fissure vein dipping 60° to the southeast. It is unique for this region in showing the results of fumarole action. The wall rock has been altered for a distance of several feet on either side of the vein. The feldspars have been changed to sericite. A lithia mica, zinnwaldite, has been developed and a number of minerals—topaz, fluorite, and wolframite—not found elsewhere in the region occur. The gangue is principally quartz and the values are in galena, which carries notable amounts of silver, 56 assays showing a range of from 1 to 148 ounces per ton. The average of 50 assays is 46 ounces per ton. It is important to note here that this association of ores, which is exceptional for this region, occurs with an equally exceptional country rock, a rare form of ore body, and the presence of unusual conditions of temperature at the time the ores were deposited.

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[1] Winslow: Missouri Geol. Survey, Vol. VII, 1894, p. 672.

[2] Contribution to Archean geology of Missouri, by E. Haworth: Am. Geologist, Vol. I, 1888, p. 295.

[3] Missouri Geol. Survey, Vol. VII, 1894, p. 701.

[4] Mine La Motte sheet: Missouri Geol. Survey, Vol. IX, 1895, pp. 83-86.

In the Cambro-Silurian series the prevailing country rocks are magnesian limestones and dolomites. Here, as elsewhere, the sandstones seem to have been distinctly unfavorable to the deposition of ores, though we must assume that, as usual, they served as the main water-bearing strata of the region. A minor amount of ore has been found in the sandstone,[1] but only in connection with veins and ore bodies better developed in the limestones above or below.

Magnesian limestones have peculiarities which exert an important influence on the form of ore bodies occurring in them. They are made up of intimately associated calcite and dolomite, the latter in turn being a compound of calcium and magnesium carbonates. These compounds differ considerably in solubility in ordinary ground water, and they differ also in other properties. There is a tendency for magnesium to replace calcium under conditions obtaining at the earth's surface, and in the change from ordinary limestone to dolomite there is a shrinkage of approximately 12 per cent in bulk. It follows that dolomite limestones are frequently vesicular in texture and full of small cavities. These form druses, and are often receptacles for ores. On a weathered face of dolomitic rock, they, together with inequalities in solution, produce the carious surface which is so characteristic of this class of rocks (see fig. 12).

Owing to the ready reaction between calcium carbonate and any magnesium solution, the general action of underground water in a series of magnesian limestones is to produce uniformity of composition. In this process bedding planes are to a considerable extent blotted out and the rock mass becomes much more homogeneous. This has an important influence in determining the form of fracture which may result from any subsequent stress.

Stresses in homogeneous materials are developed equally and uniformly to the limit of each individual block of material, and any fracture made in relieving them will follow the same rule. In massive rocks these blocks are larger than in bedded rocks, and as a result fractures of all kinds are marked by greater continuity and uniformity of direction in such rocks. The persistence in direction and close parallelism of the veins at Butte, Mont., are explained by Emmons and

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[1] Winslow: Missouri Geol. Survey, Vol. VII, 1894, pp. 694–695.

Tower[1] as a natural result of stresses developed in a granite of uniform composition. The persistence and uniformity of the ore-bearing crevices in the Dubuque lead and zinc region are believed to be due to the same causes. In the Cambro-Silurian region of Missouri the conditions are essentially the same as in the Dubuque region, and the

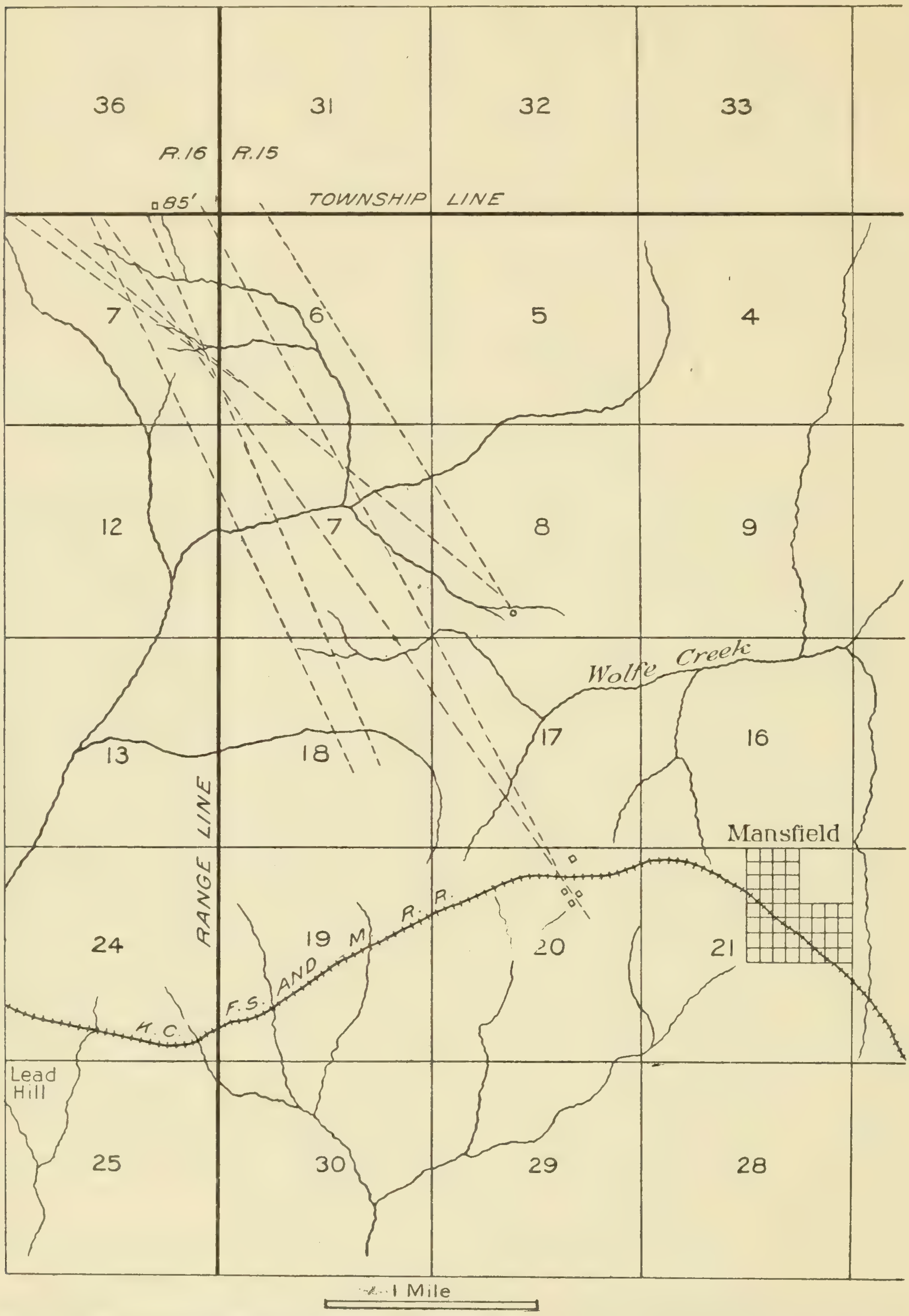

FIG. 13.—Map of Mansfield mining district, Wright County, Mo., showing principal crevices and shafts.

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[1] Geologic Atlas of the United States, folio 38, Butte Special, Montana, p. 4.

deposits in these rocks are characteristically developed in and along narrow fracture planes or fissures, which, as compared with those developed in the Carboniferous limestones, are marked by greater continuity but less breadth.

The character of these fissures is illustrated in the figures showing the crevices in the Mansfield mining district of Wright County (fig. 13) and the workings of the Dodson Company on the main vein (fig. 14). This vein, as seen in the Cormay and Mayes mine, has a dip of 80° SW. and a strike of N. 25° W. It is developed in a fine-grained homogeneous dolomite. The vein is 3½ to 4 feet wide and is made up of brecciated limestone and crystalline masses of blende. The blende fills the interstices of the limestone breccia. Calcite also in part forms the matrix. There is a well-defined foot wall with a half-inch band of black selvage, but aside from this there is not at this mine (T. 78 N., R. 15 W., SW. ¼ sec. 6) any distinct evidence of faulting. Where the vein crosses the railway track near Mansfield it outcrops in a deep rock cut and there is clear evidence of faulting. This has been described by Winslow.[1] The amount of the faulting has not been determined. It is important to note the persistence of the fractures and their general parallelism. This is further illustrated in the field by the development of a system of master joints parallel to the main fault, and is excellently shown in the railroad cut mentioned. The general uniformity of width of the vein is indicated in Winslow's description and is shown in the field. There are, however, occasional enlargements.

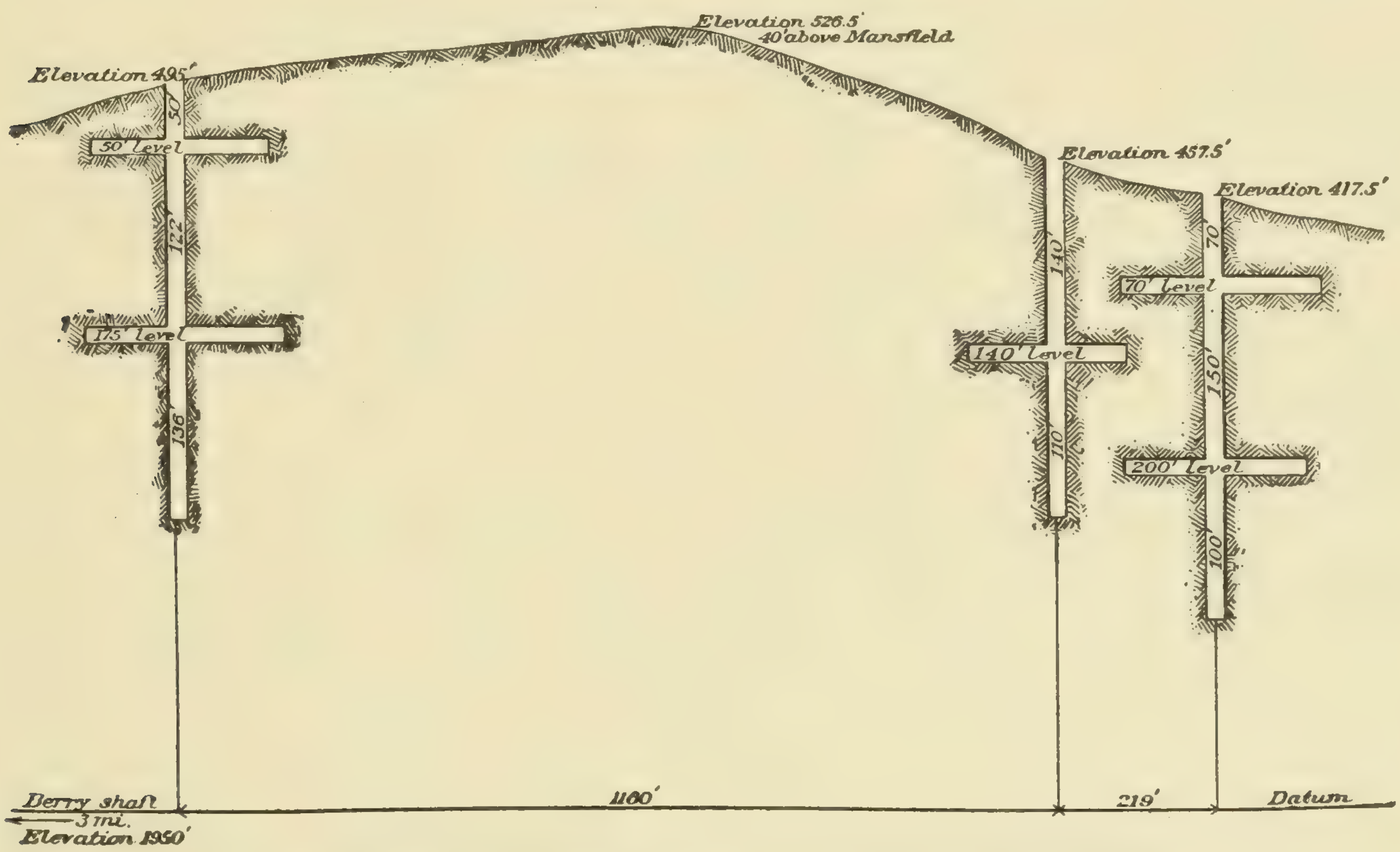

FIG. 14.—Mines of the Dodson Mining Company, near Mansfield, Mo.

A second type of ore body, which is particularly characteristic of the region where the magnesian limestones form the country rock, is that of the great irregular disseminated deposits exemplified in the Bonne Terre and other lead mines of the Southeastern district. These mines were not especially studied in the course of the present work, but the details are excellently given in Winslow's[1] maps and descriptions. The ore bodies are impregnations of the dolomitic country rock. They are very irregular in outline and very extensive. Some idea of their extent may be gained from the statement of J. Wyman Jones[2] that in 1897 there were 50 acres of underground workings in the Bonne Terre mines alone.

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[1] Missouri Geol. Survey, Vol. VII, 1894, pp. 636–638.

Dolomites are particularly subject to replacement. Their generally massive and at the same time porous character favors the wide distribution of the solutions throughout the rock rather than their concentration along definite channels and horizons, such as bedding planes. The bulk of the ore in such rocks occurs disseminated irregularly through the rock mass. Wherever there are planes of any kind ore will be developed along them, but the planes are not necessary and such ore is exceptional. In the Bonne Terre mines some of the ore is developed along horizontal planes, probably originally bedding planes. Locally the amount of this may be very great and rich sheets comparable in many features to the flats[3] of the Wisconsin region are found.

The varied strata to which the name Devono-Carboniferous has been given upon the accompanying map are in large part shales. Associated with the latter are minor amounts of sandstone and of limestone, which rarely are developed sufficiently to change the aspect of the formation. The shales are not a favorable horizon for the development of ore bodies. In general their more flexible character causes them to suffer deformation without marked fracturing. It is the exception to find well-developed fractures persisting through them. While they are essentially impervious and hence have a large influence in confining and directing underground waterflow, there is very little flow through them. Where they are cut by a fissure which has been the conduit of ore-bearing solutions they have been normally softened on either side of the fissure and impregnated to a certain extent by the solutions. The ore in such cases is precipitated in small separate and usually nearly perfect crystals, the soft and yielding shale permitting the crystals to take their proper form. The very common case of pyritic nodules in black shales is an example. In the Ozark region there is an excellent example of this form of deposit in the "pebble jack" and "pebble lead" obtained at the Star and other mines of the Pierson Creek camp in Greene County. It is also well shown in the common occurrence of a certain amount of pebble ore in Coal Measures shales overlying the Mississippian limestones in the Joplin region, as at the Mossback mine at Galena, Kans., the Massasoit south of Joplin, and elsewhere, and again where shale is brought into juxtaposition with limestone by faulting, as at the Cuban mine at Central City, the Glendale at Joplin, the No. 6 of the Boston-Aurora at Aurora, and in other mines. In all these cases it is probable that the deposition of the ore has been influenced not only by the physical character of the shale, but by the presence of an exceptional amount of organic matter, which acted as a reducing agent. The conditions are in many particulars analogous to those in the Iowa-Wisconsin region, where the "oil shale" plays so important a rôle in ore deposition.[1]

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[1] Missouri Geol. Survey, Vol. VII, 1894, 645–676; Bull. U. S. Geol. Survey No. 132.

[2] Engineering Magazine, Vol. XIII, 1897, pp. 358–366.

[3] Chamberlin: Geol. Wisconsin, Vol. IV, p. 439.

The Mississippian rocks which in the Southwestern district form the country rock, include limestones and interbanded limestone and chert. The limestones are characteristically nonmagnesian and are ordinarily crystalline. The lower strata of the limestone are unusually heavy bedded and in Arkansas often take the form of marble. The upper limestones are not often so well crystallized. They are fine to medium grained and gray to blue in color where not weathered. They are associated with large amounts of chert, some of which occurs in distinct concretionary nodules showing concentric banding and some in such shape as to show that it is a replacement, distinctly later than the limestone. Most of the chert, however, occurs interbanded with the limestones along bedding planes as if originally interbedded with it. In the quarries at Carthage, near the St. Louis and San Francisco Railway station, approximately 10 per cent of the vertical section is chert. At many places fully 50 per cent of the section is chert. In still other instances there are great beds made up entirely of chert, reaching thicknesses of 20 to 50 feet, as in the mines at Prosperity, and at Tanyard Hollow, southwest of Joplin. In some cases, as at the places mentioned, these thick bodies of chert are distinctly bedded and in all external characteristics they are similar to other bedded rocks. In other cases the whole body of the chert is massive, gnarled, knotted, and strikingly different in appearance. This phase is excellently seen at Grand Falls and other points along Shoal Creek south of Joplin.

The lithologic types common in the Mississippian limestones and serving as country rock for the ore bodies of the Southwest are (*a*) the massive chert just mentioned, in which the ore is developed mainly at the contact of the chert and one of the other types; (*b*) massive limestone, which rarely is important, and when important is associated with dolomitization and a tendency toward metasomatic replacement by the ores; (*c*) interbanded chert and limestone. The last-mentioned type is by far the most common and deserves particular study. It affords conditions especially favorable for ore deposition, because the interbanding gives a large number of horizontal contact planes for the circulation of underground waters, because, the ready solubility of the limestones leaves open spaces both for the circulation of the waters and the deposition of the ores, and because, owing to its brittle character, the chert is shattered very irregularly and extensively by even slight stresses and thus affords passages for circulation. The many bedding planes in the rock cause the fractures to be extremely irregular. Solution of the limestone leaves great masses of broken chert in which the ores are deposited in very irregular form, which may be especially well seen in the Center Creek mines at Webb City.

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[1] Blake: Trans. Am. Inst. Min. Eng., Vol. XXII, p. 629. Calvin and Bain: Iowa Geol. Survey, Vol. X, p. 572.

The chert referred to in this connection is to be sharply distinguished from the secondary or later chert, probably derived in part at least from solution of the earlier chert. The later chert commonly serves as a matrix to the ores. The differences between the two have already been noted. The origin of the older chert is not here in question. The field evidence is quite conclusive that it is distinctly older than the fracturing and the incoming of ore-bearing solutions. If it be considered a replacement of portions of the limestone, its formation is to be correlated with an early circulation of waters which brought about an almost complete recrystallization of the limestone. It is significant that, while the evidence indicates that this movement of the water was widespread, the water was clearly confined to this particular formation. This is shown by the fact that the recrystallization was not accompanied by any development of minerals containing elements not found in the limestone itself. The practically complete absence of dolomite, for example, in the Mississippian limestones of the entire Mississippi Valley, except in close association with the ore deposits, when considered in connection with the wide recrystallization of the limestone itself, points to absence of magnesium up to the time of introduction of solutions from some extraneous source. These solutions did not come in until after the recrystallization of the limestone and the possible replacement by chert.

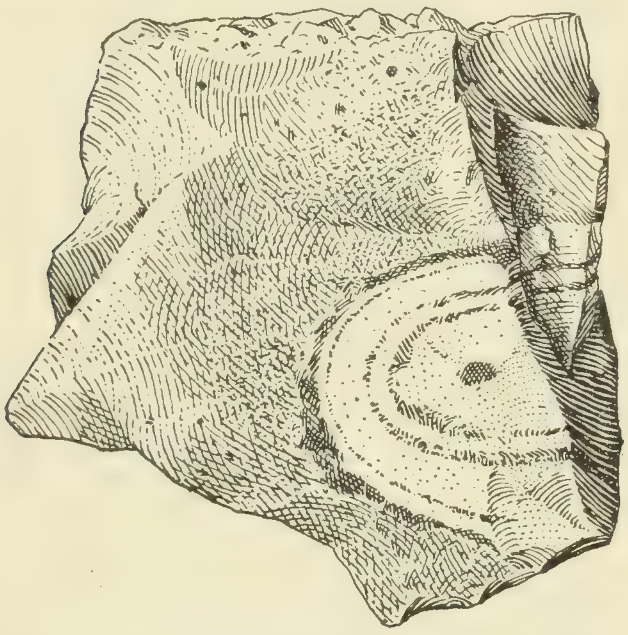
Fig. 15.—Concretionary form of earlier chert, Carthage, Mo.

The gnarled and knotted appearance of the chert at Grand Falls, with its somewhat irregular geographic development and the presence in it at the Redding mine of undetermined fossil sponges, point to a possible original deposition of the siliceous material through the agency of these forms. However the siliceous material may have been originally deposited, whether as sand distributed throughout the beds or as amorphous silica at particular horizons, there have apparently been important changes since its deposition. This is shown by the presence of distinct concretionary structure in some of the chert (fig. 15) and by the formation of nodules and blocks of chert at angles with the bedding planes. The outline of the chert bodies is also suggestive at times of replacement of the limestone (fig. 16). All these changes, however, are distinctly earlier than the deposition of the ores and have had no influence on the latter.

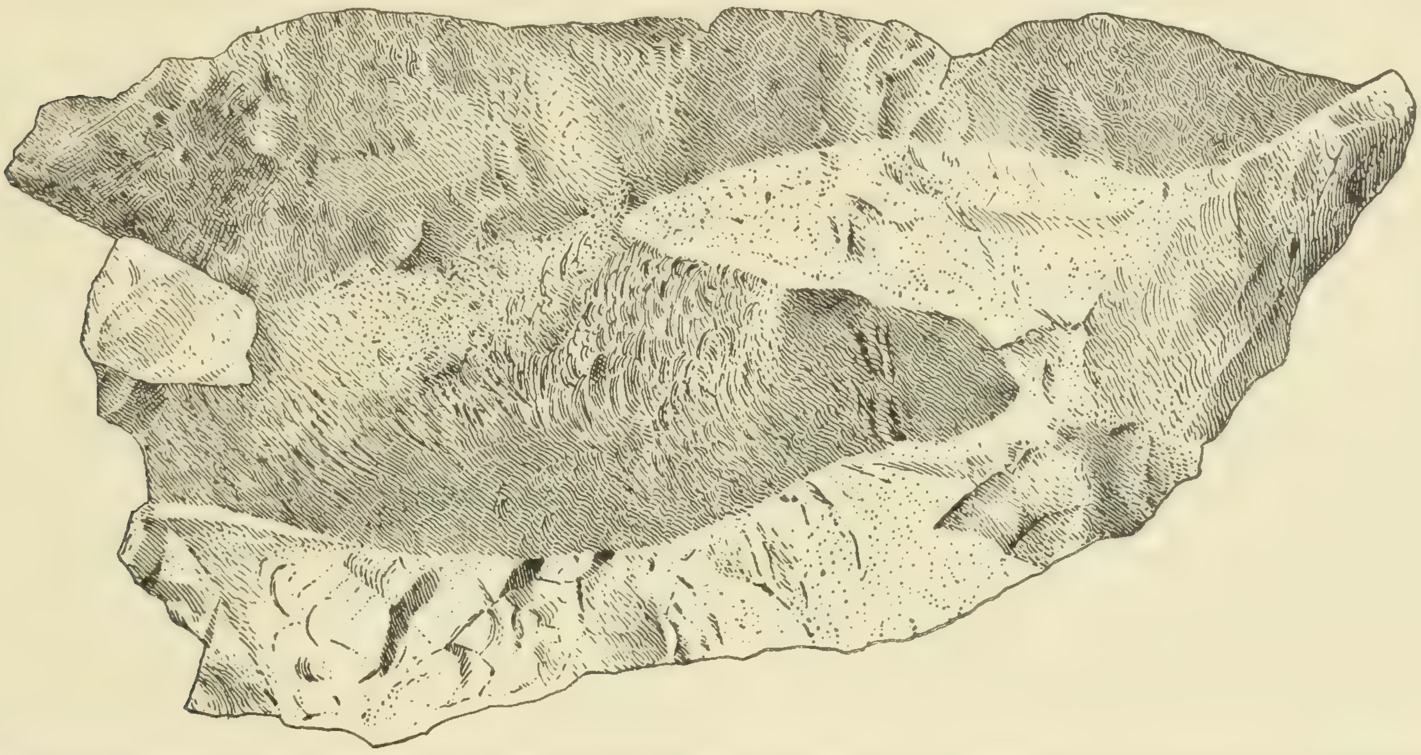

FIG. 16.—Irregular form of earlier chert, indicating its origin by replacement, Lone Elm, Joplin, Mo.

The overlying Coal Measures shales rarely contain important ore bodies except at the plane of contact with limestones. They do not in a general way serve as country rock to the ore bodies, and while their influence on the formation of ore has seemingly been very important, it is in other particulars, which will be discussed later.

FORM OF THE ORE BODIES.

In form the ore bodies of the Ozark region show wide variety. Occurring throughout the whole of a series of strata stretching from the pre-Cambrian to the Carboniferous, inclusive, and in rocks of widely different lithologic character, it is impossible that the ores should not take a number of different forms. While they are all due to the same general agencies, individual deposits have been changed by the different conditions under which these agencies have been compelled to work. The results have also been greatly influenced by a long period of surface erosion.

In general, the ore bodies are modified fissure deposits, though in probably a majority of cases the individual ore body is so irregularly developed that the original fissure form is unrecognizable, and a comparison of the ore bodies with the fissure deposits of Western mining regions is in most cases more misleading than helpful. Since, however, the term fissure vein has been occasionally applied to them, their resemblances to and differences from that form of deposit will be discussed. The ores are, except in the case of recent and strictly surface deposits, genetically related to certain fractures and fissures. Jenney's generalization[1] that "all workable deposits of ore occur in direct association with faulting fissures traversing the strata and with zones or beds of crushed and brecciated rock, produced by movements of disturbance" is amply sustained by the present observations so far as it applies to the district studied in detail. Perhaps the form of the statement makes the idea of faulting a little too prominent, since in many cases no notable displacement is known to accompany the individual fractures. Faulting is, however, clearly of importance in connection with certain stages of the genesis of the ores. Detailed evidence of this is given in connection with many of the descriptions of the special maps of the Aurora district and the Continental tract at Joplin, as well as in notes on the Massasoit, Pleasant Valley, and other mines, It is not to be understood that the actual form of the ore body is often that of a faulting fissure, but it is equally wrong to assume that the ores have filled cavities which were entirely independent of fracturing. In general, fracturing and solution have cooperated to produce cavities, and the form of the cavities, which was determined by the character of the country rock, has in turn largely determined the form of the ore bodies.

Fissure veins.—The distinction between fissure veins and crevice deposits is not easy to make. In both forms the ore occurs in narrow, usually vertical or steeply dipping sheets, in most cases cutting across the country rocks. Each sort of ore body may have a considerable extent and persistence with depth, though both of these characteristics are usually more pronounced in the case of fissure veins.

It is true that in general fissure veins show a banding or crustification of the vein material, while crevice deposits do not; and that fissure veins usually occupy fracture planes, while crevice deposits are in solution-enlarged cavities or cracks. Any line drawn between the two is more or less arbitrary. In this report fractures, when accompanied by notable faulting, will be referred to as fissures and the ores developed along such fractures will be called fissure veins. Fractures not accompanied by notable faulting will be spoken of as crevices and the ore bodies found in connection with them will be called crevice deposits. Fissure veins are characteristic of the ore bodies of the Ouachita Mountains as distinguished from those of the Ozark uplift. In the latter region the fissure vein is so rare as to be practically absent. The type is, however, approached in certain of the mines of the Central and Southeastern districts. In the Southwestern district typical fissure veins are not known. The ore bodies there always show a tendency toward irregular development and metasomatic replacement, a process which, as Lindgren has recently shown,[2] is commonly associated with fissure veins. One of the best developed fissure veins in the Ozark region is that on which the Einstein mine, already described, is located.

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[1] Trans. Am. Inst. Min. Eng., Vol. XXII, p. 181.

[2] Metasomatic processes in fissure veins: Trans. Am. Inst. Min. Eng., Vol. XXX, p. 578.

True fissure veins are the rarest type occurring in the region. The veins found in southwestern Arkansas are mainly of this type. The Bellah mine of the North American Ore and Metal Company may be taken as typical. This mine is located in Sevier County, Ark. (secs. 27 and 28, T. 7 S., R. 32 W.), about 6½ miles southwest of Gillham, which is on the Kansas City, Pittsburg and Gulf Railway. The mine was worked during the civil war by the Confederate government for lead, and the slag and furnace remains indicate that work was carried on for some time. The country rock is a black shale, presumably of Lower Carboniferous age. The vein is well defined and cuts across the beds with a strike of E. 8° N. At the surface it is practically perpendicular, but in depth it dips toward the north, the dip at 145 feet being 80°. In the vicinity of the mine the vein has been developed by test pits for a distance of about a thousand feet, and a vein, supposedly the same, has been traced several miles. The vein has been developed to a depth of 160 feet with drifts both east and west at 50 and 115 feet. The old workings from which the lead was taken were above the 50-foot level. At present at the 115-foot level and below, blende is the most important ore. With it are minor amounts of galena and chalcopyrite. The galena was abundant in the upper workings, which were also said to carry more chalcopyrite. The vein is 3 to 8 feet wide and has well-defined walls showing both vertical and horizontal slickensides. It carries abundant sharp-angled pieces of the country rock and a large amount of quartz, which occurs in part in small crystals lining the vugs and druses in the vein and in part in streaks and bands running through the vein. It is also comby and is arranged with the ore in ribbon structure, though there is no uniform sequence for the vein as a whole. The wall rock on either side shows evidence of shearing in thin partings filled with quartz. In all these particulars the Bellah is a typical fissure vein. The mines in the same vicinity, the Davis,[1] the mines at Antimony City,[2] and others are located on veins of the same general type. Many of the Franklin County, Mo., veins approach the fissure vein in character.[3] Of these, the old Virginia mine is perhaps the best known. It has been described by Litton,[4] King, and Winslow.[5] The Merrimac mine, which is supposed to be located on the same lead (secs. 28 and 33, T. 42 N., R. 1 E.), was visited in the course of the present work.

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[1] T. B. Comstock: Report upon prelim. exam., etc.: Rept. Arkansas Geol. Survey for 1888, Vol. I, 1888, p. 146.

[2] Comstock: loc. cit., pp. 136, 141. C. E. Wait: Trans. Am., Inst. Min. Eng., Vol. VIII, 1880, pp. 42–52.

[3] Winslow: Missouri Geol. Survey, Vol. VII, 1894, p. 693.

[4] A. Litton: Missouri Geol. Survey, Pt. II, 1855, pp. 22–26.

[5] Winslow: loc. cit., p. 696.

At the Merrimac mine the country rock is a fine to medium grained dolomite of considerable uniformity, rather coarsely bedded. The partings carry little clay, but a small amount of chert is present along the bedding planes. The rocks have a gentle dip to the north and east and pass under a coarse-grained sandstone 30 to 40 feet thick. This in turn passes under the magnesian limestone, which underlies the Pacific sandstone, and accordingly the ore deposits here are presumably in the Third Magnesian Limestone of the older classification. The vein has a strike of N. 25° E., and has been developed by surface pits for a distance of about a quarter of a mile. It dips to the east 70° and has been developed by shafts to a depth of over 100 feet. These shafts are connected by horizontal levels so that about 900 feet along the vein is open underground. The main shaft head is 110 feet above a nearby stream. Water stands in the mine at a depth of about 90 feet. This seems to be the normal ground-water level and has not apparently suffered any important recent change. At the surface the vein is, where now open, about 20 inches in width, and is made up of barite, galena, and red residual clay. The galena occurs in crystalline masses in the barite (fig. 11), and as loose pieces in the red clay. At the 30-foot level in the main shaft the vein is only 2 to 4 inches in thickness. At the 90-foot level it varies in width from 2 to 4 feet. Throughout the mine the hanging wall is particularly well defined, but the foot wall is not always distinct. The hanging wall frequently shows well-developed slickensides, and there is clear evidence of faulting in the sharp cutting off of the limestone beds and in interbanded chert nodules along the fault plane. There is also a certain amount of post-mineral faulting, as is shown in the development of slickensides and drag phenomena along the edge and in the ore body itself. The amount of faulting was not determined. Brecciation is very subordinate, though well developed in the Lost Hill and other mines in the vicinity. At the lower levels the ore body is made up mainly of blende. Above and near the water level this is altered to smithsonite, the carbonate. Throughout the mine barite forms the gangue. Red clay, abundant at the surface, is found in decreasing amounts down to water level. Calcite is locally and irregularly developed in quantity on the lower levels especially, but dolomite, except in the country rock, seems absent. To a limited extent galena and blende occur together, but throughout most of the mine they seem to have been separated by the processes which bring about segregation of the galena above and the enrichment of the blende below. No pyrite was noted.

An example of the form which fissure veins take in the Southwestern district, and which might with equal propriety serve as an example of a crevice deposit, is seen in the vein worked on Pierson Creek in Greene County. The mines, known locally as the Gumbo mines, have been especially well described by Shepard.[1] Additional notes are given by Winslow.[2]

At present the Star mine is the most important one working, and was visited by the author. The ore in this consists mainly of a very high-grade blende, with a subordinate amount of galena and a very little pyrite. It is pebble ore, and occurs mainly free in the blue-clay shales of the Kinderhook. The ore body is 14 feet high and 10 to 18 feet wide. It narrows at one point to 5 feet in width. It has a fairly persistent course of N. 26° W., and is nearly vertical, but dips to the east. The west wall is a hard, blue limestone, well bedded and apparently barren. The mass of the ore body is soft shale or gumbo. The east wall of the ore body is not well defined, and is quite irregular. The ore runs out into it in flat sheets, lying between the bedding planes. A similar sheet 4 inches thick, made up of practically clean blende, occurs along the bottom of the drift now open, extending to the west wall of the crevice. The east wall is made up of what miners call limestone bowlders, and which seem to be, as suggested by Winslow, merely harder and perhaps more calcareous portions of the shale. The roof is a hard blue but noncrystalline limestone, and dips from the west wall, as sketched in fig. 17. The ore is richer against this roof, and indeed here, as throughout the soft-ground mines of the Southwestern district, the ore is most abundant against the hard bounding walls.

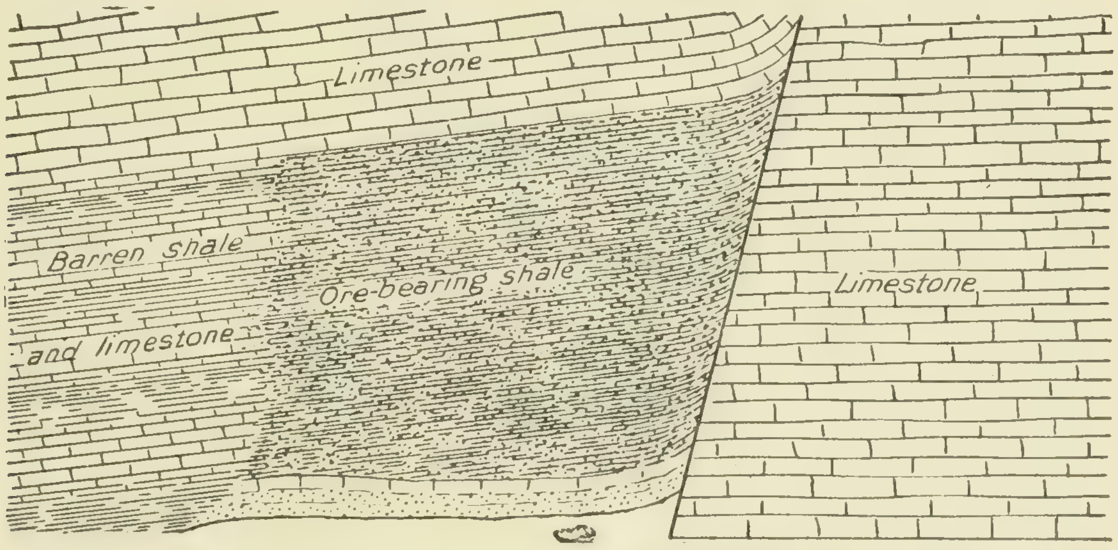

FIG. 17.—Face of ore in Star mine, on Pierson Creek, Greene County, Mo.

This mine is on a fissure, or possibly a group of fissures, running approximately N. 30° W., which have been traced for a distance of somewhat over a mile. There is some displacement in connection with the fractures, as shown in the mine and in the bluff. It is not certain that the amount is great. Shepard determined a fault of 20 feet at one point, but in the exposure shown in fig. 18 the amount of of displacement does not exceed 2 or 3 feet. This particular figure is interesting because it shows the change in the size of the ore body as the fissure passes from the softer limestones of the upper member of the Boone formation into the denser layers below. It is from a photograph of an exposure in the bluff near the Sunrise shaft, and is introduced through the courtesy of Professor Shepard.

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[1] Geology of Greene County: Missouri Geol. Survey, Vol. XII, Pt. I, 1898, pp. 174-182.

[2] Missouri Geol. Survey, Vol. VII, 1894, pp. 624-626.

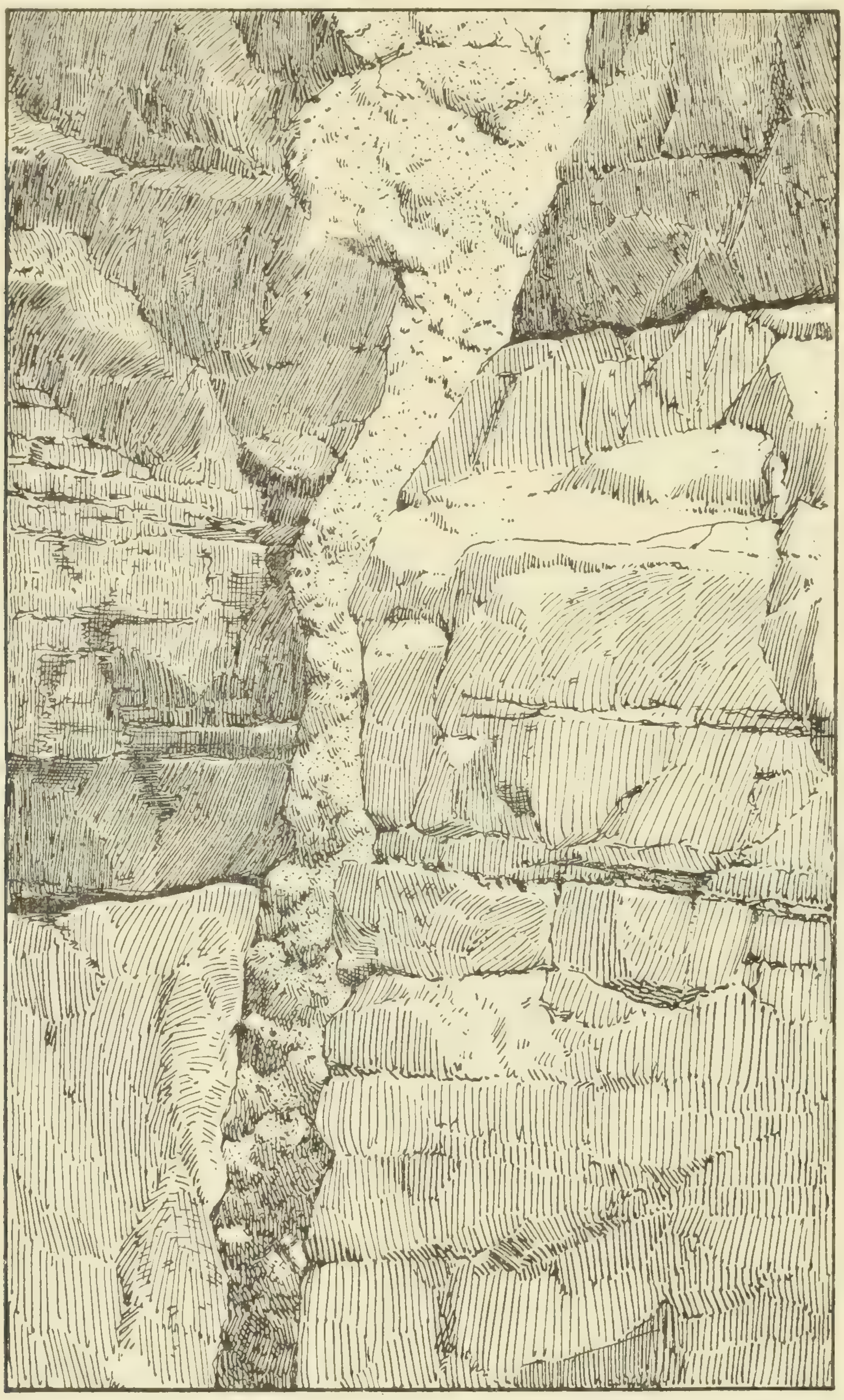

FIG. 18.—Fault with development of breccia and ore body in Boone formation, Pierson Creek, Greene County, Mo.

A certain amount of horizontal faulting is suggested by the behavior of the ore body in the Nathalie mine. Here, in following the ore to the northwest, a series of offsets of 15 to 30 feet to the west were encountered. These were so regular that it soon became possible to calculate quite accurately where the continuations of the ore body should be.[1] Such phenomena might well occur in a series of parallel crevices or faults as a result of the ore-bearing solutions finding their way from one fissure to the other through cross fissures, and do not necessarily imply that there was actual horizontal displacement of the rock.

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[1] Shepard: loc. cit., p. 175.

The main fissure here, and to a less extent the subordinate ones, show the persistence of the fracturing through several different formations, and indicates clearly that the openings are not simple joint planes confined to individual formations. The section exposed in the bluffs at the mine is given below:

Pierson Creek section.

	Feet.
4. Slope, largely covered with residual chert but with occasional outcrops of coarse crystalline limestones interbanded with some chert	±20
3. Limestone, bluish, dense, hard, color	60
2. Limestone, yellowish buff, soft, granular	25
1. Shales, blue, argillaceous, mainly seen in the mines	20

The upper member of this section belongs to the upper portion of the Boone formation. No. 3 represents the lower member of the same formation. The two succeeding beds and probably some 20 feet of additional strata below are portions of the group here referred to as the Devono-Carboniferous, the strata present being those known specifically as the Chouteau limestone and the Vermicular shales. The fissures extend downward through these strata, changing in size and character in each formation. This is illustrated in the figure already given.

The same phenomenon is shown at the Lang mines in Christian County, and has been described by Shepard.[1] This mine was visited, but the conditions were not favorable for detailed observations. Enough however, was seen to make clear the continuity of the fracture and the change in form of the ore body with change in the nature of the inclosing strata.

The description given will emphasize the fact that while in the Southwestern district faulting fissures occur and ores are associated with them, they are so different in character and development from the form of veins elsewhere defined as "true fissure veins" that it is a mistake to define them as such. Consideration of their probable persistence with depth may properly be left for later discussion.

Crevice deposits.—Among the ore bodies of regular form crevice deposits are by far the most common in this area. As has been indicated they are closely related to fissure deposits. The term is here restricted to ore bodies of regular form developed in fractures made without especial faulting. As distinct from the common irregular bodies, crevice deposits have usually quite well-defined walls and definite courses. They show all gradations toward both fissure veins and irregular deposits The term is used to cover veins which are often called gash veins.

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[1] Loc. cit., p. 171.

Crevice deposits are much more abundant in the Cambro-Silurian than in the Carboniferous beds for the reason already given—that under equivalent stresses the former fracture much more regularly.

The most typical occurrences are probably those of Washington County, Mo. At Potosi, in this county, the ore occurs in sharply defined crevices, cutting across the dolomitic country rock in directions parallel to the major joint cracks. The crevices are from a few inches to 10 feet wide, and are worked to depths of approximately 100 feet. Individual crevices may be traced a half mile or more across the country. The crevices show a tendency to expand at certain definite depths, and form openings in which the main ore bodies or "runs" of ore occur. At Potosi, at least, these openings are commonly associated with shaly partings in the rock. As usual, galena with a matrix of barite and red clay occurs above water level and with depth gives way to blende, associated with barite and minor amounts of calcite and brecciated country rock. The ore bodies here are remarkably similar in form to those of the Iowa-Wisconsin region, where crevices have been traced for distances of 5 miles and worked to depths of 200 feet and over.

Runs.—The term run is the one locally applied to the ore bodies, particularly in the Southwestern district. Jenney defined a run as "an irregular ore-body, formed at the intersection of an ore horizon with a vertical fissure."[1] In this sense the actual ore bodies found in the crevices just described are the most typical runs. It will be convenient, however, to extend the term slightly and apply it to the somewhat irregular and yet not wholly formless ore bodies which are especially characteristic of the Southwestern district, even though they spread out very considerably from such an intersection. As noted by Jenney, these ore bodies occur at horizons which, because of their physical or chemical peculiarities, are especially favorable to ore deposits. An excellent example of such a horizon is seen in the thick body of interbedded limestone and flint which so commonly forms the upper 80 to 150 feet of the Boone formation as it occurs in the Southwestern district. It is in these strata that most of the ore so far developed in the immediate vicinity of Joplin has been found. The favoring characteristics are the large number of bedding planes between the chert and limestone, the soluble character of the limestone, the brittle character of the chert, and the wide presence of notable amounts of reducing material. In such strata, broken and softened, ore-bearing solutions wander widely and deposit irregularly.

On the special map of the Continental tract the distribution and ground plan of some of these ore bodies are shown on a very much

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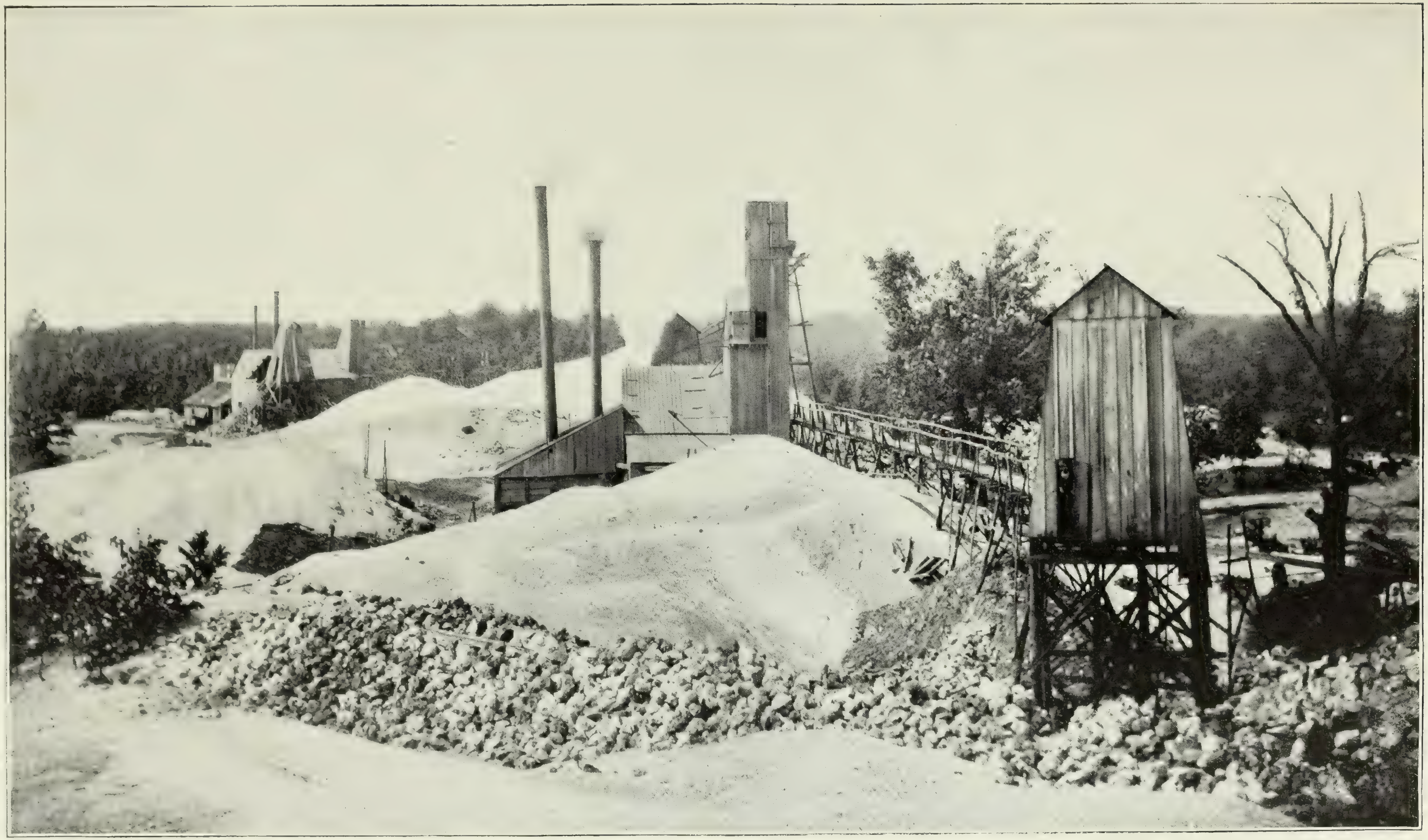
[1] Loc. cit., p. 189.



LINEAR ARRANGEMENT OF SHAFTS ALONG THE ARKANSAS RUN, BELLEVILLE, MO.

reduced scale. Similar runs are shown on the Aurora map, and Winslow has shown the same phenomena in a special map of the old Empire tract at Joplin. This map is reproduced below (fig. 19).

One of the best defined runs of the district is the Arkansas run at Belleville. This has been developed across seven mining lots, or for

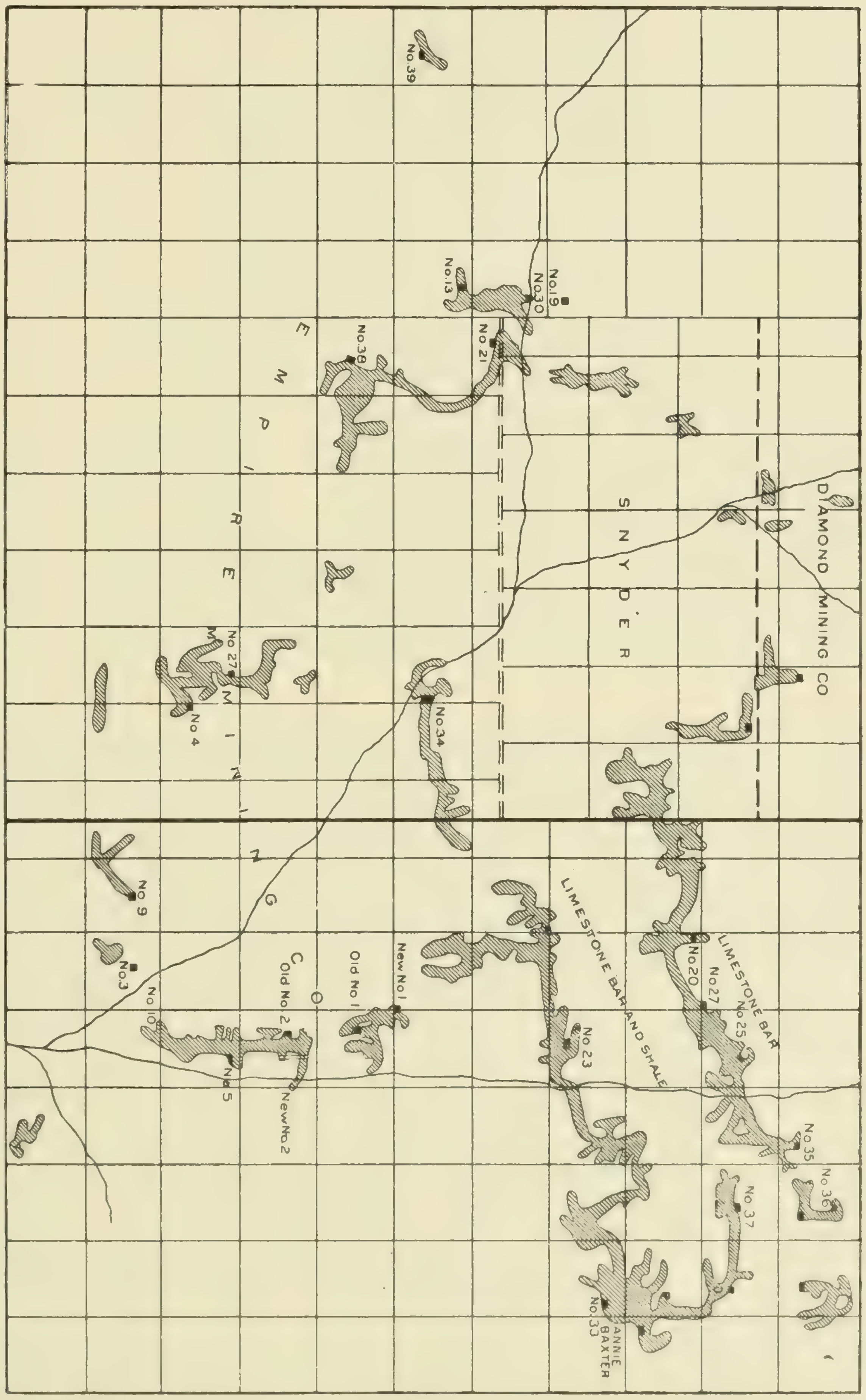


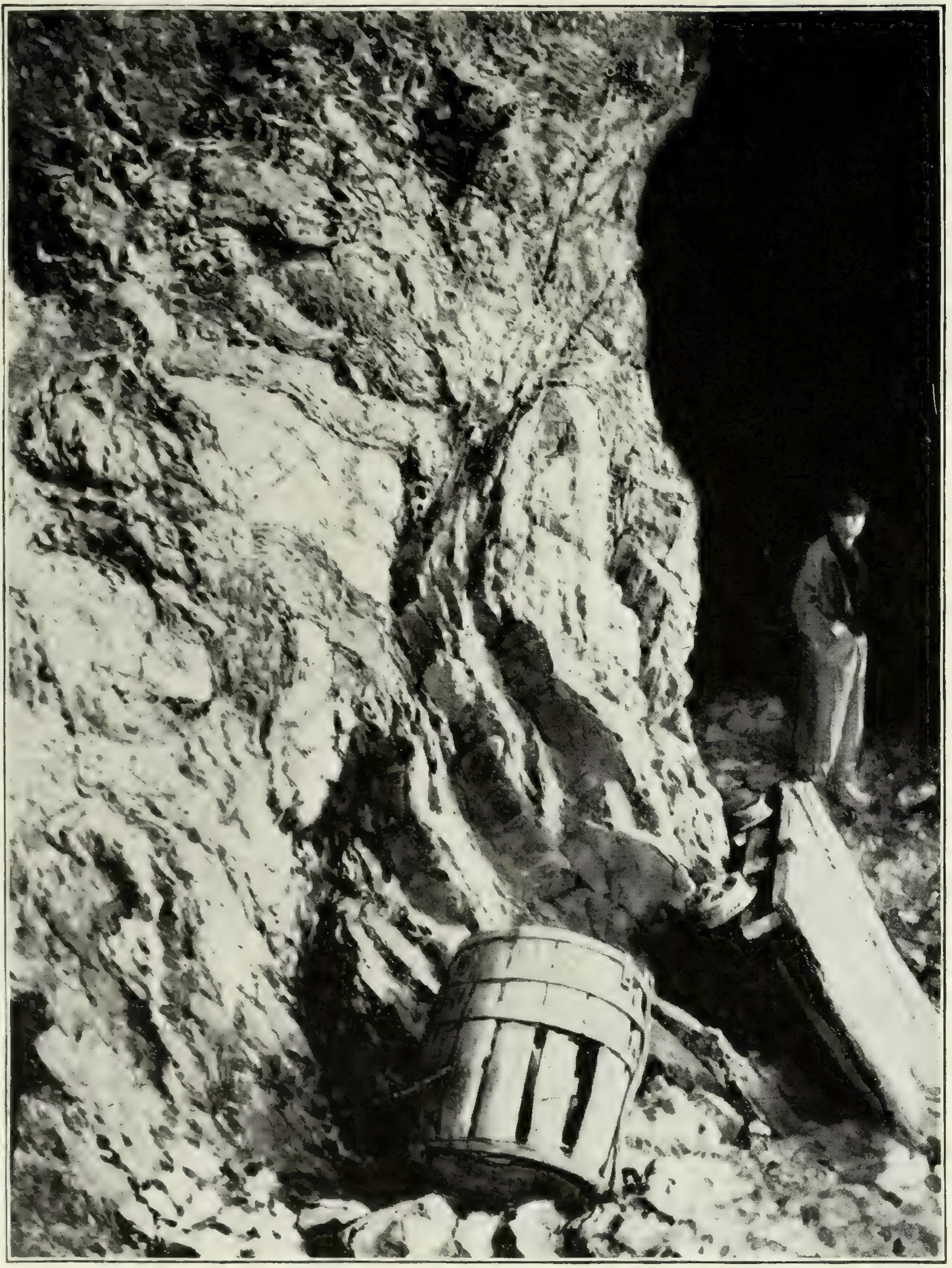
Fig. 19.—Underground workings on the Empire tract, near Joplin, Mo. (after Winslow).

a length of 1,400 feet. The course varies from south to east, but the general direction is southeast. There is a dip, as seen in the Arkansas mine, of 75° to 80° to the northeast. The hanging wall is usually the better defined, and frequently shows slickensides. When exposed it is seen to be a coarsely crystalline, horizontally bedded limestone. The run is from 12 to 30 feet wide, and the ore is mainly developed at the 90-foot and the 150-foot levels. The former shows a capping of 30 feet of partially ore-bearing breccia. The main workings at the 150-foot level extend upward irregularly, occasionally connecting with those of the upper level. The run is essentially an irregular brecciated mass developed along a faulting plane. It is made up of crushed flint with dark-gray granular dolomite for the usual matrix. Occasionally blocks of dark-black limestone are found, these standing in sharp contrast with the angular blocks of white chert. Pockets or vugs, filled with soft, black mud or lined with pink dolomite crystals, are occasionally found, but are not common. The rocks in the foot wall are made up of normal flint and limestone, somewhat broken and probably displaced. In that direction Coal Measures shales are found at a depth of 135 feet between bars of hard limestone. These bodies of shale are not known to have any considerable lateral extent, and no certain evidence was noted of their having been faulted. Beyond this shale to the southwest, in the Eagle mine, horizontally bedded and undisturbed chert and limestone form a bar or wall against which ore has been deposited. In the Arkansas mine the ore more commonly "makes" or occurs against the hard hanging wall. The Arkansas ores are quite clean blende, and contain very little pyrite. No alteration products, calamine, or smithsonite were noted, and very little red clay is found, most of the ore occurring in ordinary gray spar. In the Arkansas mine very little bitumen is found, but in the Eagle it is present. In the latter mine calcite is also abundant.

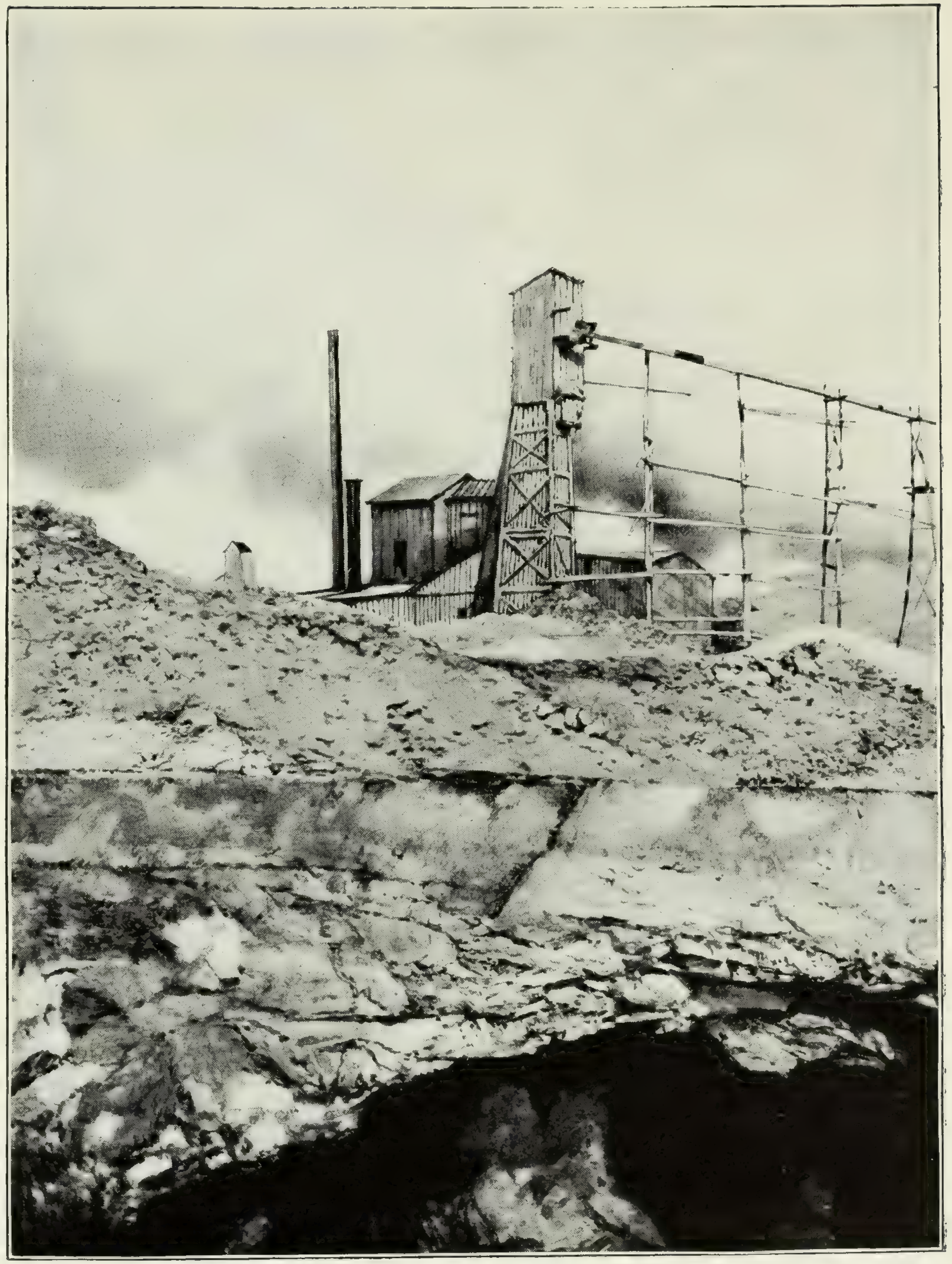
The Arkansas run represents one almost extreme type, an impregnation in direct association with a faulting fissure. The famous mines along Center Creek, between Webb City and Cartersville, represent the other extreme. The ores at the latter locality occur in a broken chert, in connection with abundant black clay known as "selvage." They occur at the horizon normally represented by interbedded flint and limestone, but here the soluble portion of the limestone has been removed and only the insoluble portion remains. Over portions of the area the upper heavily bedded limestones have been removed, though they are shown at certain points, as in the rim of the Nevada sink.

This upper limestone carries a minor amount of blende and galena in disseminated form, but the rich ore bodies which have made the district famous are found below it. The district is cut by a series of faults, some of which can be seen in the open pits (Pl. XII) while others are better seen in the mines. The latter will be more particularly described in connection with notes on the mines of the Missouri Zinc Fields Company. The extreme irregularity in the form of these ore bodies is shown in fig. 20, redrawn from a map of the region by S. J. McKee. The map shows the ground plan. Vertical sections would show the ore bodies to be quite as irregular in outline.

The nature of the ore body is especially well seen in the Nevada



A. FAULT IN BRECCIATED LIMESTONE OF CENTER CREEK VALLEY, WEBB CITY, MO.



B. NEVADA SINK, CENTER CREEK VALLEY, WEBB CITY, MO.

sink, which is illustrated in Pl. XII, *A* and *B*. This sink, which was formed by the caving in of old workings, is approximately 800 feet in diameter and 40 feet deep. The rim of the sink is formed of a dark coarse-grained holocrystalline limestone showing on fracture clear calcite and small crystals and crystalline masses of galena and blende. This limestone is 12 to 20 feet thick and is undisturbed and unbrecciated. Great blocks of it lie in the pit where they have fallen. Below the limestone and dipping with it 14°, strike N. 88° W., is a body of sheeted rock made up of limestone similar to that above, interbedded with clear white chert. It is this portion which is so largely broken up and which forms the ore-bearing breccia of the region. In the breccia the fragments of white chert at this place are not notably splintery. When individual pieces are picked out of the breccia they show rounded, pitted, and papillate surfaces, suggestive of solution rather than fracture. Elsewhere the chert is clearly fractured, and, indeed, fractured chert is the rule for the district. The white flint contains no ore except in definite cracks or seams, nor has it apparently had any influence chemically in bringing about ore deposition. Ore does not especially cluster around the chert as it does sometimes around limestone fragments. The normal matrix is a dark, calcareous material, apparently siliceous to a variable degree, ranging in composition from a black secondary chert to a similar black secondary limestone. Calcite occurs in seams and lining small water channels, in which latter situations crystals of pink dolomite are also occasionally found. In places the matrix becomes a soft black mud. Mud is rare at this point, but more common on adjacent mining lots. The ore, which at levels now open is mainly blende, occurs irregularly massed and disseminated in the matrix. At some points in the vicinity soft ore-bearing ground extends up to the surface, while at others the heavy cap of limestone seen at the Nevada sink is present. Brecciation is widespread and very irregular and the distribution of the ore in the breccia is equally irregular. There is, however, at many points, at least, a notable tendency for the ore to segregate in the vicinity of small slips, crevices, and other water channels.

Breccias are especially characteristic of the Southwestern district, as would be expected from the nature of the rocks occurring there. At the same time they also occur to some extent in the other districts. Brecciation is often an accompaniment of close parallel fracturing, as at the Morning Star mine, at Rush, Ark., and the Hoppe mine, near Smithville, in the same State. The Michigan mine opposite Buffalo, Ark., also shows a zone of brecciation impregnated by ore, and the Bonanza mine, on Cow Creek, in the same vicinity, is essentially of this type. Horizontal or bedded breccias, such as occur in northern Arkansas, are primarily conglomeratic in genesis. These are discussed in some detail on page 199.

Blanket veins.—The term blanket vein is used here to cover tabular bodies of ore developed parallel to the bedding planes of the rocks. For reasons already given the bedding planes, and in particular contact planes between two sorts of rock, are especially favorable horizons for the movement of underground waters. They become, therefore, common ore horizons. A body of ore developed in such a situation is a blanket vein. Blanket veins may be developed in three ways: (*a*) by simple metasomatic replacement of a particular bed; (*b*) in a breccia resulting from differential movement between beds; (*c*) in residual material or in cavities left after the partial solution of a bed. Each of these forms has representatives in this region. The first class is best developed in the Southeastern district. The second and third classes are commonly found together throughout the region, since differential movement and solution usually have gone together.

The best example of the type of blanket veins in the Southwestern district is what is known as "sheet ground." This is frequently developed in and around Cartersville, Mo. The normal section of the strata in this vicinity is given below:

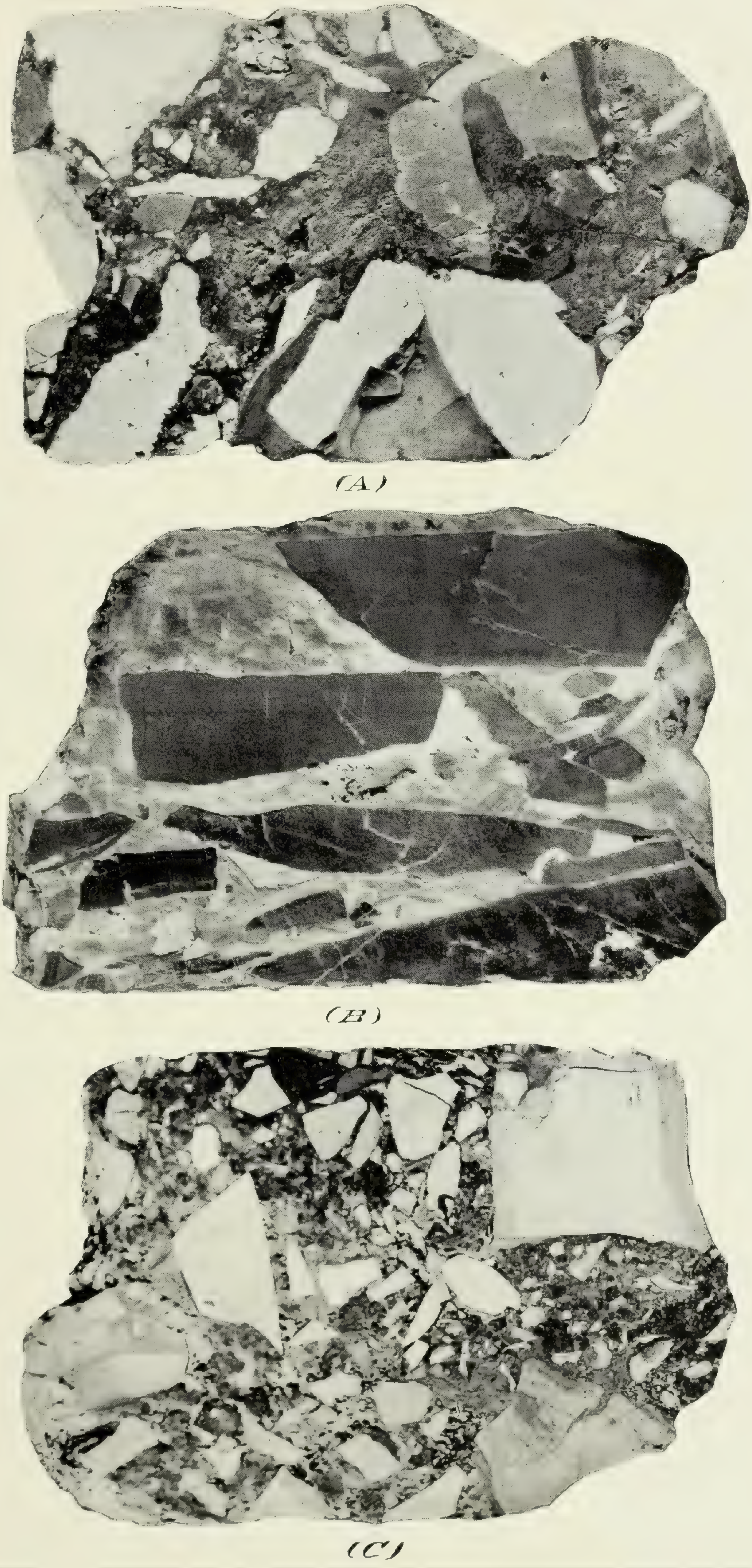
Section near Cartersville, Mo.

	Feet.
4. Soil and loose material	15– 20
3. Limestone and chert, horizontal and interbedded	150–170
2. Chert, rather massive, but showing bedding planes	30– 50
1. Limestone, blue, crystalline, with some interbedded chert	75+

No. 3 of the above section represents the beds in which the Center Creek breccias are developed. In the sheet ground the bulk of the ore is developed at the top of the heavy chert, No. 2, and along the bedding planes in the chert to a depth of 5 to 20 feet. It is stated that ore is also found at the contact between the chert and the underlying limestone, but so far this horizon has not been developed.

The general character of the sheet ground ore body is shown in Pl. XVI, reproduced from a specimen obtained in one of the mines on the Boston Get-There tract. Between horizontal layers of white chert are thin bands, from 2 to 8 inches in thickness, of black, secondary chert, which acts as a matrix for the brown crystalline blende. In the specimen figured there seems to have been no differential movement between the strata, but in others such a movement is suggested by the sharp, splintery surfaces of the white chert bands and the presence in the black matrix of angular bits of white chert. Cavities are developed along the bedding planes, and in them are beautiful assemblages of blende, galena, marcasite, greenockite, and other minerals, which will be more particularly discussed in connection with the subject of secondary enrichment.

Sheet ground is common in many workings in the Cartersville-Prosperity region which have gone to sufficient depth to get into the main body of the chert. It may be seen in the mines of the Missouri Zinc Fields Company, the Missouri Blanket Vein Company, the Modoc,



CHARACTERISTIC BRECCIAS OF THE OZARK ORE DEPOSITS.

A, From Continental land, Joplin, Mo.; *B*, from Michigan mine, Buffalo, Ark.; *C*, from Peoria, Ind. T

and others. Between these areas are regions of disturbed rocks, where ore occurs in the very irregular form as seen along Center Creek. Some of the mines on the Eleventh Hour ground are particularly good examples of the latter form.

Blanket veins are developed in the North Arkansas district under somewhat different conditions. At the Morning Star and Mackintosh mines on Rush Creek the ores are developed at the intersection of a zone of vertical fissuring and certain limestone conglomerates. These conglomerates and oolites seem to have afforded favorable conditions for the lateral spreading of the ore solutions, and there is accordingly a tendency toward the blanket form in the ore bodies. Similar conditions were noted at other Arkansas mines, though how important this may be in fixing the extent of the ore bodies was not determined.

Disseminated ores.—Disseminated ores are those which have no regular form and usually no sharp boundaries, but in which the ore occurs as small crystals or crystalline masses irregularly scattered through the country rock itself. They are the result of impregnation of the country rock by ore-bearing solutions. The ore crystallizes out in the cavities of the rock, when there are cavities, or replaces the rock by metasomatic processes (substitution particle by particle) when there are no cavities. There are two types of disseminated ores which are common in the Ozark region. The first is the pebble ore already described as occurring in the soft shales, and most commonly found in the Southwestern district; the second is the ore to which the term is more frequently applied, and is especially exemplified in the great irregular bodies of galena found in the dolomitic limestones at Mine La Motte, Bonne Terre, and other mines of the Southeastern district. These mines have been well described by Winslow,[1] and the description will not be repeated.

In the Southwestern district a certain amount of disseminated ore occurs, though it is not, as compared with the ore breccias, important. The presence of disseminated ore in the hard upper limestones at the Nevada sink has been already referred to. Under the microscope this ore has an appearance very different from that in which the later chert forms the matrix for the blende. The groundmass is made up of an intimate mixture of quartz and calcite with irregular boundaries. The blende is unevenly disseminated and does not usually show good crystal forms. Some crystal boundaries occur on it, but there are also lugs and arms reaching out into the spaces between the quartz and calcite grains. Large crystals of calcite and blende showing good crystal form occur only in veins traversing the rock.

In Chitwood and Leadville hollows, northwest of Joplin, the limestone usually shows more or less disseminated ore. Such ore is in most instances closely associated with the ore breccias, and shows all gradations from a simple impregnation of the near-by country rock to complete replacement. Replacement apparently has been accomplished by a metasomatic process essentially similar to that by which a portion of the limestone has been dolomitized. Metasomatic replacement is especially associated with the development of large irregular beds of ore, such as these of the southeast, but it is to be remembered that it is a process rather than a form of deposit, and may occur in connection with any form of ore deposit.[1] Where ores are developed in limestones it is common, but probably the widespread fracturing and development of breccias in the Southwestern district, by affording even more favorable conditions for ore deposition, have served to make it relatively rare there.

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[1] Missouri Geol. Survey, Vol. VII, 1894, pp. 645–700. Bull. U. S. Geol. Survey No. 132.

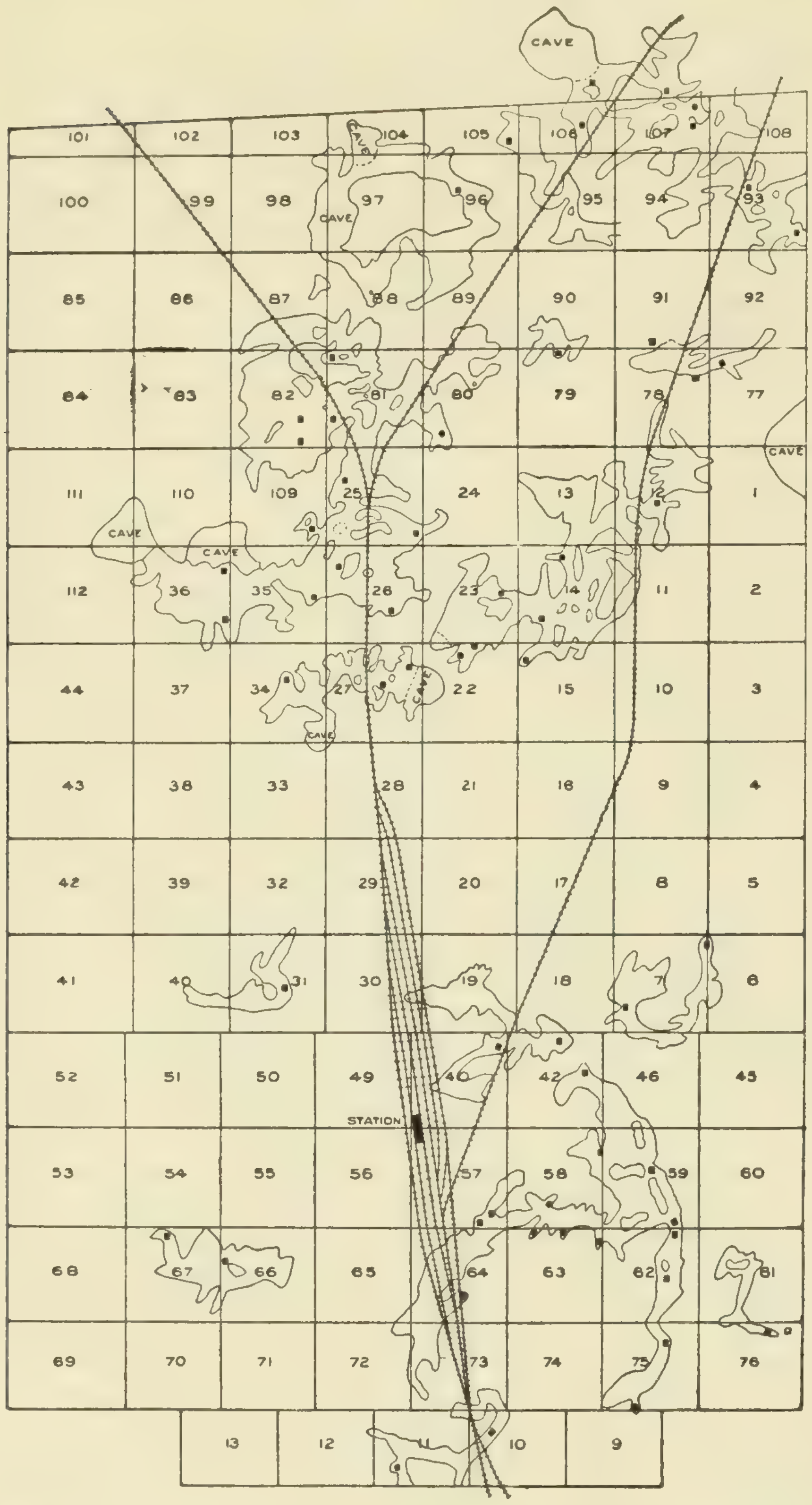

FIG. 20.—Underground workings in Center Creek Valley between Webb City and Cartersville, Mo.

Circle deposits.—A form of ore body relatively common in the Southwestern and Central districts is the one known as a circle. Some of the richest ore bodies have been found in a form which, in ground plan, has a circular outline, and as a result the circle deposit has come to stand in the popular mind for a rich ore body. These circles are of various sizes. The diameter of the Conlog circle in Miller County is given by Winslow at 80 feet.[2] The Oronogo circle, the one on the northern portion of the Missouri Zinc Fields land, and one in Center Creek Valley at Webb City, near the Missouri Pacific station, all of which are represented in accompanying figures (figs. 20, 21, 22), are approximately 300 to 400 feet in inner diameter and 500 to

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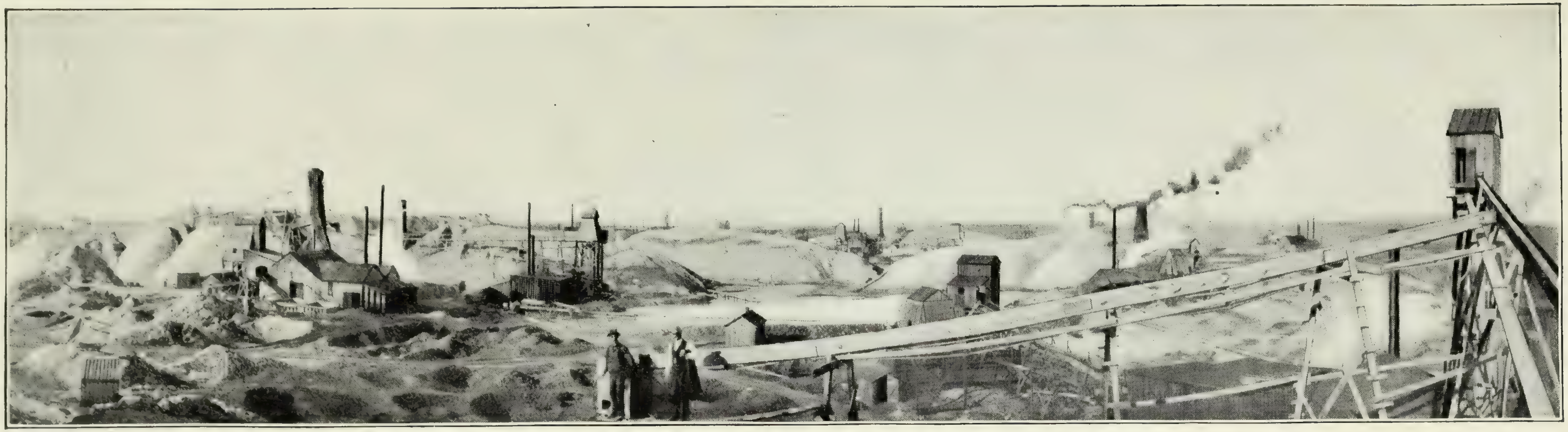
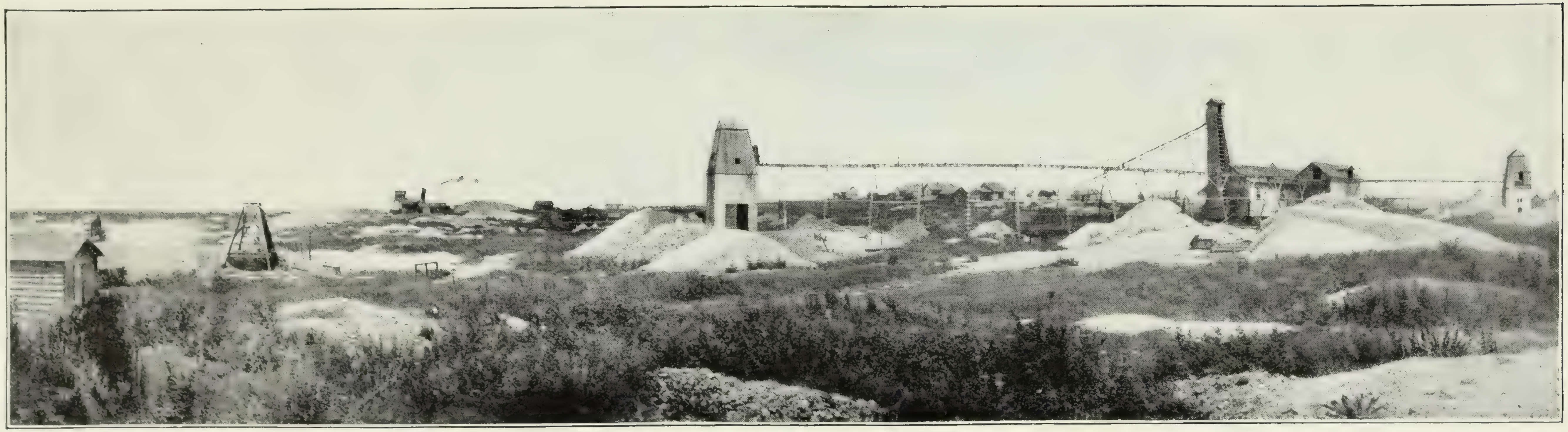
[1] Origin and classification of ore deposits, by C. R. Keyes: Trans. Am. Inst. Min. Eng., Vol. XXX, pp. 330-331. Metasomatic processes in fissure veins, by Waldemar Lindgren: Trans. Am. Inst. Min. Eng., Vol. XXX, p. 578.

[2] Missouri Geol. Survey, Vol. VII, 1894, p. 707.



A. MINES OF THE ORONOGO CIRCLE. ORONOGO, MO.



B. WAR EAGLE MINE. NORTH HEIGHTS, JOPLIN DISTRICT, MISSOURI.

600 feet in outer diameter. The circular outline is general and not exact in any case. These circles are usually, if not always, associated with more or less shale presumably belonging to the Coal Measures.

Adolf Schmidt[1] studied the Oronogo circle in particular in 1873 and considered it essentially a sink hole, "caused by the erosion of a large cavity in the underlying limestone, and by the breaking down of the upper strata." In this general explanation of circle deposits Schmidt was followed by Winslow. It is not improbable that certain circle deposits have been formed as suggested by Schmidt. Indeed, the Conlog circle, as described by him and by Winslow, and other circles in the Central district, seem clearly of this genesis. It is not believed, however, that this is the correct explanation of the larger circles. The Oronogo, Granby, and Missouri Zinc Field circles have been studied in some detail and were found to be so closely related to certain definite fault planes that it is impossible to refer them to the category of sink holes. The circle form as developed by mine maps is to a considerable extent deceptive. An examination of a large number of mines and mine maps shows apparently that the circle deposit has obtained an undue prominence in the popular mind. There are quite as many S-shaped or V-shaped ore bodies, and if the early and richer mines had chanced to be ore bodies of this form it is conceivable that the miners would now be attempting to exploit these deposits rather than circles. In any series of ore bodies developed along intersecting fractures curved forms are bound to be common and do not necessarily imply any peculiar conditions of fracturing.

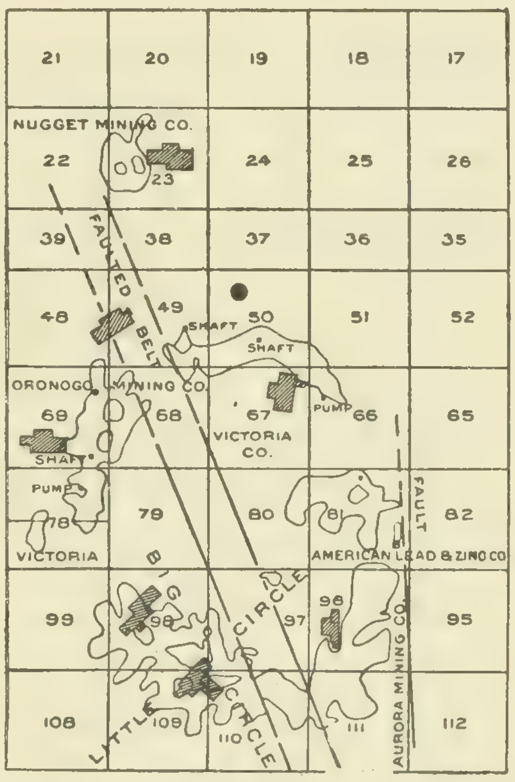


FIG. 21.—Underground workings of the Oronogo circle, Oronogo, Mo.

The underground workings of the Oronogo circle are shown in fig. 21, redrawn from a map by S. J. McKee. The drifts lie about 140 to 150 feet below the surface, the various shafts represented being from 115 to 173 feet deep. Formerly the circle was worked by surface pits and the small workings shown in the eastern part of lot 81, at a depth of only 58 to 70 feet. The depths given are in each case to the bottom of the drift. The stopes extend upward ordinarily 25 to 35 feet and exceptionally 60 to 115 feet. The mines are located in a small topographic basin which has, on the southwest side especially, a rough circular outline. The basin opens out to the north and is merely the head of one of the common draws or shallow side valleys of the region. The earliest work was around the edge of the circle, where surface deposits of galena were found. The ore bodies followed the semicircular contour of the hill. The galena was found principally in a red clay matrix, and the lead seems to have represented the common concentration on hillside slopes by descending recent waters. As the mines reached greater depth the red clay in most cases gave way to a black selvage and in some cases to the ordinary chert matrix. In lots 69 and 78 the red clay and oxidation influences persist even to the present depth of mining. The ore bodies of the lower levels, however, consist mainly of a breccia of white chert with a black, earthy to siliceous matrix of varying hardness. Ore—a practically clean blende of exceptionally high grade—is irregularly disseminated throughout the matrix. Some calcite occurs in seams and little druses, but on the whole calcite is rare. Limestone does not occur in the mines of the west side of the circle except in disintegrated blocks, known to the miners as bowlders. Bitumen was not noted and dolomite is relatively rare. Around the edge of the breccia at several points, in lots 68 and 69 in particular, the ordinary horizontally bedded white chert, with a little interbanded limestone, occurs unbroken. At such points blende is developed in thin sheets or flats along bedding planes in a hard, black chert matrix of later origin.

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[1] Lead and zinc of southwest Missouri: Rept. Geol. Survey Missouri, 1873 and 1874, pp. 484–487.

The circle is cut by a fault along which a narrow block of Coal Measures shale is dropped down approximately 140 feet. The position and course of this fault is indicated in fig. 21. In lot 68 it passes between the Oronogo and Victoria workings and cuts off the drainage of the one from the other. The shale may be seen in the roof of the northeast stopes of the Oronogo mine in lot 68. Below it is the unbroken or sheeted ground noted above. At one point this undisturbed chert was cut through by a horizontal drift, and at a distance of 14 feet ore was found on the east side in the usual breccia. In the horizontally bedded rock there is a well-developed series of vertical fracture planes parallel to the general course of the fault. These are so pronounced as to control the methods of blasting.

The shale is seen again in the Big Circle and Little Circle workings in lots 97, 98, and 110. It lies mainly above the present workings and the drift in lot 110 connecting the Big Circle and Aurora mines crosses under the shale which shows clearly in the roof. In lot 97 the fault block cuts off the drainage of the mines to the west of it from the pump shaft to the east on levels below 140 feet. There is free drainage between this pump shaft and the American mine to the east.

That this is a fault block is shown, first, by the tabular form of the block of shale, and the linear course of the fault; second, by the presence of broken pieces of flint, shale, and coal in the main body of shale along the contact; third, by the relatively unbroken and clearly unoxidized condition of the ground below the slate, which forbids reference of the phenomena to the pre-Coal Measures erosion; fourth, by the orientation of cracks and seams of calcite parallel to its course; fifth, by the development of a crush breccia and ore bodies along its sides. This latter phenomenon is well shown in the mines lying southwest of the fault block. In lots 68, 97, and 98 the largest and richest ore bodies were found along the edge of the slate body and running off from it irregularly to the southwest. In lot 78 there is an excellent face of ore to the east toward the fault, and there is every indication that that portion of lot 79 lying southwest of the fault block will prove to carry rich ore.

There was no opportunity to make a complete study of the mines of the circle which lie east of the fault. The Victoria mine was closed. From the fact that its drainage is reported to be entirely independent of the other mines of the circle it is inferred that the mine may be located on a cross fracture, which, however, there was no opportunity to demonstrate. In the American mine a well-developed fault having a course N. 10° W. and a dip of 51° to the southwest was seen in the upper workings and is shown on the map. This fault has been traced in the mine for a distance of 100 feet. To the east is a wall of hard, horizontally bedded limestone. To the west is a crush breccia of flint, with the fragments showing drag phenomena along the contact. No slickensides were noted, but the difference in material on the two sides of the fault and the arrangement of the fragments leaves no doubt of the faulting. The amount of throw was not determinable.

Ore is developed in the breccia along the west side of the fault. At the surface and for some distance below galena occurs in a red clay matrix. At the level now worked there is some galena, a good deal of calamine, and some blende. The matrix is in part red clay and in part the later black chert. The ore body in this instance increases in size with depth so far as it has been worked. It will be noted that the lower workings in this mine and in the Aurora, as represented on the map, extend eastward to a rather definite boundary line parallel to the fault plane traced in the upper workings and about as far to the west as would be expected from the hade of the fault. The lower workings were not accessible at the time the mine was visited, so that it can not be positively affirmed that the ore is there cut off by the fault. It is, however, very probable that this is true.

These facts lead to the conclusion that the ore bodies of the Oronogo circle stand in close and definite relations to fault planes which intersect at an acute angle. The circle is formed by development of ore along sides of the wedge-shaped area between the intersecting faults. The ore body of the Victoria mine may be developed along some slight cross fissure or may represent merely the general tendency of underground waters to circulate widely in broken ground. The ore-bearing solutions coming in along the two fissures may have wandered laterally until they met and mingled midway.

The whole of the area between the two faults is more or less broken.

A drill hole near the intersection of lots 67, 68, 79, and 80 showed that the upper portion of the Mississippian limestones, which should normally be made up of interbanded chert and limestones, was thoroughly broken. Practically all the limestone has been carried away by solution, and more or less blende is found in the broken chert to a depth of 213 feet. The record of the hole as reported may be summarized as follows:

Section near intersection of lots 67, 68, 79, and 80.

	Feet.
9. Soil and gravel	0– 21
8. Shale with small pieces of coal and pebble galena, blende, and pyrite	21– 63
7. Chert, broken and carrying more or less blende	63–213
6. Chert, solid ledge, barren	213–263
5. Chert, with some blende	263–286
4. Chert and limestone interbedded	286–310
3. Limestone	310–340
2. Shale and shaly limestone	340–380
1. Limestone	380–400

The heavy bed of chert, No. 6, is doubtless the one commonly found in the region and described in connection with the notes on blanket veins (p. 142). The beds below, No. 3 to 5, represent the lower member of the Boone formation. No. 2 represents the Devono-Carboniferous, and as usual is reported to have shown both blende and pyrite. No. 1 doubtless represents the upper beds of the Cambro-Silurian. The shales at the top of the section, No. 8, belong to the Coal Measures. The fact that the Coal Measures here are dropped down 63 feet only while along the western edge of the fault they have been thrown down more than 100 feet, may be interpreted to mean either a tipping of the fault block to the west or a series of parallel faults of differing throw. The latter is believed to be more probable, since such zones of fracture are common phenomena in the district.

A second instance of a circle deposit that is closely related to faulting planes, is illustrated in fig. 22. This circle is on the northern portions of the tract of land belonging to the Missouri Zinc Fields Company at Webb City. The sketch is reproduced from the company's map. The area is located at the intersection of the irregular run of ore already noted as followed by Center Creek and the great zone of fracture which extends from Webb City southeast to Prosperity. The mines are on low land. Over the area mapped there are irregular patches of Coal Measures shale, erosion remnants, which extend in depth usually to 20 or 25 feet. The heavy body of chert which carries the sheet ores of the region is found where there has been no faulting, at a depth of 140 to 150 feet. Between this chert and the overlying shale, or in its absence the surface, there is sometimes the hard interbedded chert and limestone which normally should occupy the interval. Along Center Creek, which crosses the northern portion of the tract, this portion of the section is much broken up. The limestone usually has been removed by solution, and there remains a chert breccia with a black selvage or a black chert matrix, such as has already been described in connection with the notes on the Nevada sink. There may or not be a hard limestone roof over this breccia, and the breccia itself may be soft and muddy, dry, but easily picked to pieces, or firmly cemented by secondary chert. Variation in this particular seems to be controlled by the extent to which recent waters have acted on the material. There is a large amount of dolomite, frequent crystalline calcite, some bitumen, and some secondary limestone in the breccia. The ore occurs in all of the materials of the breccia except the fragments of original white chert, which, as usual, are barren. Blende and galena are found together, the latter in subordinate amounts, even in the hard ground. In the soft ground blende is notably dominant. As usual, galena was found to dominate in the red clays of surface workings.

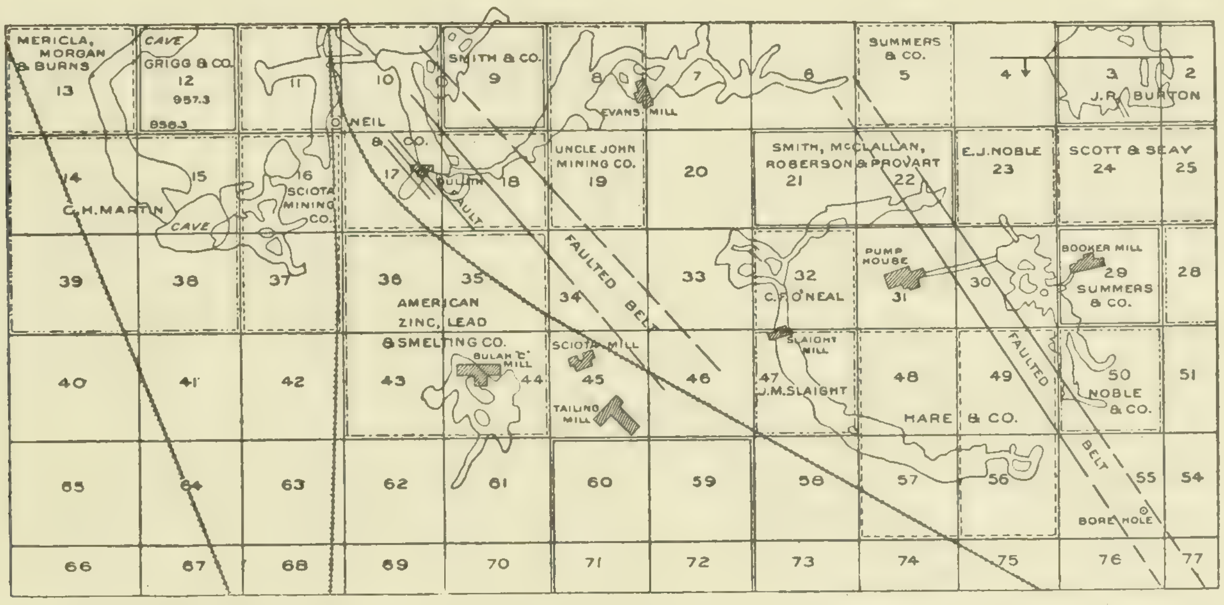


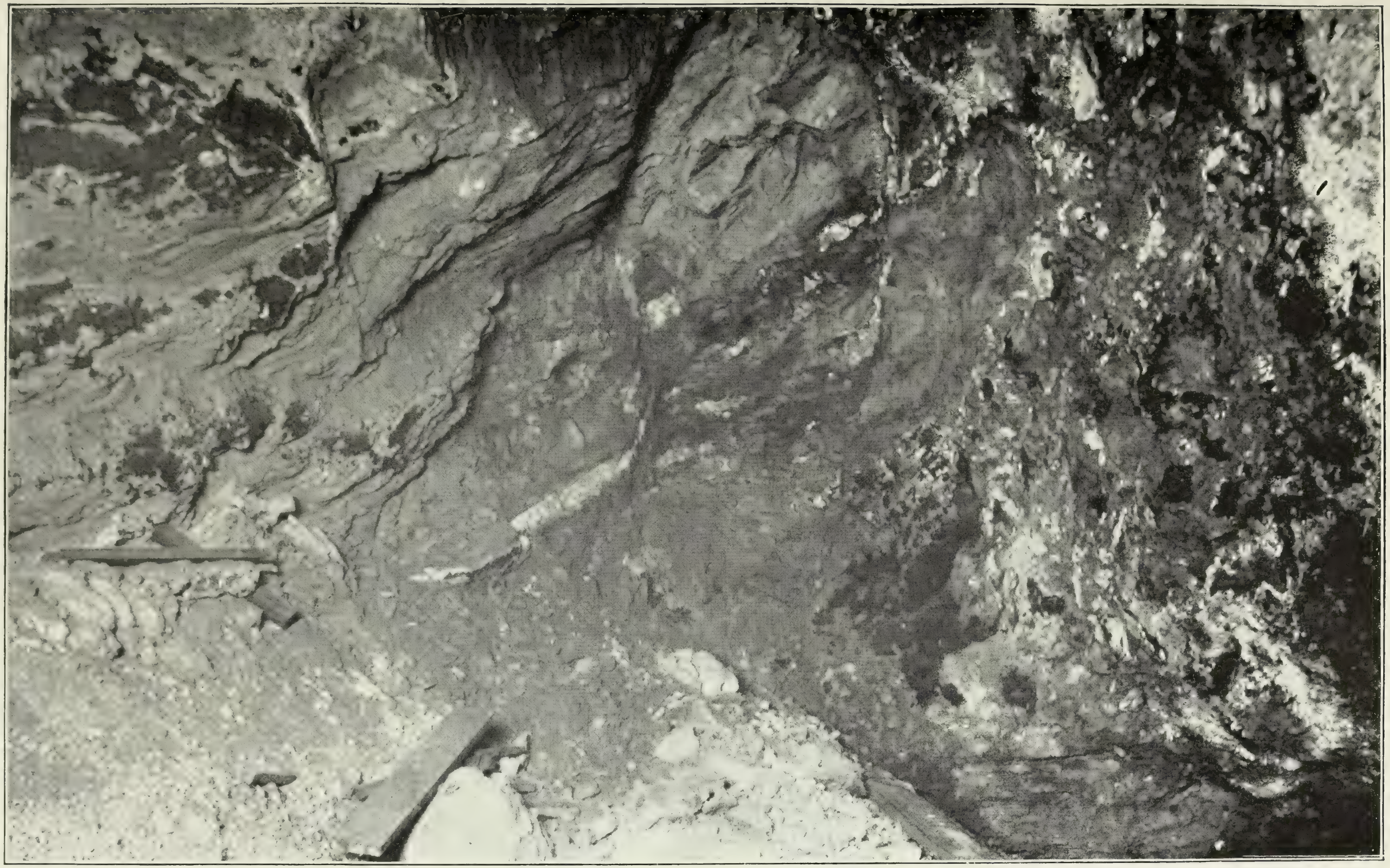
FIG. 22.—Underground workings of the northern portion of the Missouri Zinc Fields Company's tract at Webb City, Mo.

The area is cut by a series of faults having slightly different courses, but a general direction to the southeast parallel to the run of ore before mentioned as developed at intervals from this point to Prosperity. A few of the more important faults are located on the map. The main fault cutting across the circle may be examined in lots 50, 55, and 56, where the workings now extend across it at depths of 100 and 140 feet. The fault has caused the downthrow of a block of Coal Measures shale, approximately 100 feet in width, and is accompanied by compression phenomena. The limestone is thrust up over the shale at several points. The shale itself consists of alternating bands of soft, argillaceous material and hard, sandy layers. At the fault plane the material of the softer layers is bunched and not drawn out, as would be the case in tension faulting. Slickensides are developed both on the shale and such limestone as is present. Parallel to the fault is a broad zone of crush breccia in which the ore was developed. This breccia is now loose and the matrix is soft. Probably at the time the faulting took place the breccia was not yet formed, or it would have relieved the stress. The same pressure which produced the compression phenomena along the fault block crushed the normal interbanded limestone and flint. Waters coming into the crushed material along the fault plane deposited the ore and dolomite, dissolved and carried away most of the limestone, recrystallized what remained as a matrix and at places formed the black flint which cements the whole. The softening of the ground is believed to have taken place later.

The fault block may be again seen in lot 22. The conditions at this point are illustrated in Pl. XV, reproduced from a photograph, and are so clearly those of faulting that no comment is believed to be necessary.

The drift extending from the pump shaft in 31 to the mine workings in 30 was not visited, but from the fact that it is reported to be in a "bar" it is believed to cut across the fault block. The workings east of the fault block are evidently developed along the contact, and in lot 56 good ore is being found on the west side, parallel to the course of the fault. The reason for the swinging off of the main workings in a semicircle is not altogether clear. In lot 18 is a fault block seen in the Duluth and Evans mines, having ore developed along either side. The course of this fault projected would bring it near the west edge of the circle. Either this or an intermediate fault may have served to open up the ground along this line. The workings to the west in lot 33 show an increasing amount of Coal Measures shale in the breccia, and apparently indicate nearness to a fault of some kind. At several points in the western portion of the circle there is evidence of minor cross faulting, but the facts were not sufficient to warrant generalization.

The main ore body in these mines is developed in a breccia resting on the top of the heavy flint member of the formation, and, indeed, at many points the upper portion of this flint shows good sheet ground. Waters entering the breccia would tend to spread along this contact and very minor cross fractures would serve to give direction to the flow. There have been important cross stresses, as shown by the exposure in the open pit in lot 3—a body of Coal Measures shale at least 40 feet thick and dipping S. 25°. A rich body of ore was found under this shale, and the east-west course is roughly parallel to the old workings in lots 6, 7, 8, 9, 10, and 11 of this ground. The general trend of the Center Creek workings and many minor faults in the region have the same direction. The circle on the Missouri Zinc Fields land is therefore developed in the angle between two nearly parallel but converging fault blocks, and probably has been influenced in form by cross fracturing. The famous circle southwest of Granby, which will be discussed later, shows similar relations to fault planes.



FAULT IN SLAIGHT MINE, WEBB CITY, MO.

NATURE OF THE ORE BODIES.

The ores of the Ozark region as a whole belong to the class discriminated by Van Hise,[1] as formed by a first concentration by ascending waters and a second concentration by descending waters. There are individual deposits which to all appearances have not been modified since the first concentration, and there are those in whose formation downward-moving waters appear to have been the dominant agent. In most cases the ores as originally deposited have been modified considerably. The changes have accompanied and in a large measure are the secondary results of the erosion which has cut away hundreds of feet of strata that formerly overlay the district. The changes are those everywhere incident to superficial alteration of ores. By them the sulphides have been largely changed to sulphates, oxides, carbonates, and silicates. Incident to this process there has been a notable migration of material and redeposition of the ores as sulphides in druses and post-mineral fractures in the original ores. This particular phase of the general process is known as secondary or sulphide enrichment, and the large bodies of rich blende mined in the Southwestern district owe their richness largely to this process. This whole group of altered ore bodies will be discussed under the general head of ores of the second concentration. It is recognized that ores secondarily concentrated may be either ores of the first concentration or ores already reconcentrated one or more times. The general result of superficial processes is to produce a rich upper zone in ore bodies, and the ore in this zone may have migrated and changed form a number of times. An important result of the general process of alteration has been the bringing about of an orderly vertical arrangement of the various ores.

ORES OF THE FIRST CONCENTRATION.

Neglecting all recent changes and considering the ores only in their unmodified form, the three dominant processes concerned in the formation of the ore bodies seem to have been (1) dolomitization, (2) deposition of metallic sulphides, and (3) silicification. To some extent these processes were contemporaneous or recurrent, but as a whole they occurred successively in the order named. Dolomitization, it is true, was active after the main deposition of the ores proper as well as before, and there was a second deposition of sulphides after this second period of dolomitization, which may still have occurred before the influences of erosion became effective in the particular ore body. The general order given is nevertheless, observable, throughout the district, though it is the order in which each process became dominant rather than a hard and fast order of influx of differently charged waters.

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[1] Some principles controlling deposition of ores: Trans. Am. Inst. Ming. Eng., Vol. XXX, p. 173.

Dolomitization is here considered only in so far as it is related to the deposition of ores in this region, and excludes for the present the dolomitization which produced the country rock of the Cambro-Silurian region. As thus restricted the process has taken two forms, producing two sorts of dolomite. These are commonly known to the miners of the Southwestern district as gray spar and pink spar and have been already described. The gray spar mainly represents a metasomatic replacement of a part of the surrounding nonmagnesian rock. It very commonly is associated with the ores, as at the Arkansas mine and others already described. Dolomitization usually influences the country rock for considerable distances from the trunk channels. Deposition of the sulphides does not extend so far. As a result the ores are often deposited on or against a bar of dolomitic limestone. It is not believed that this necessarily indicates that dolomitization was notably earlier than deposition of the sulphides. As already suggested, it may have resulted from the greater rapidity with which magnesium sulphate diffuses through a solution than do sulphates of the metals occurring here. Nevertheless, the main sequence of dolomitization, deposition of sulphides, and silicification was probably a time sequence.

In the mines of Chitwood and Leadville Hollows dolomitic wall rock is common. On this wall rock the metallic sulphides are deposited, and in it to a less extent they occur as small, scattered crystals of blende and galena, apparently representing in the main metasomatic replacements. At the Colorado mine, northwest of Cave Springs, the gray spar is a mass of interlocking curved rhombohedral crystals, and a very finely divided blende occurs in the interspaces, apparently having crystallized in these cavities. In general the gray spar may show all degrees of mineralization, from simple impregnation to complete replacement, as at the Bessie, Grace 1, and Grace 2, and other mines of Leadville Hollow.

After its formation the gray spar was at many points fractured in such a manner as to produce long, narrow, sheet-like openings. These have been filled by the metallic sulphides, calcite, and very frequently by the pink dolomite or spar. The association of pink and gray dolomite is often so close as to give the appearance of original interbanding. This was noted among other places in the vicinity of Joplin at the Chitwood Hollow mines, the Estrada, the Mildred, and other mines on the Boqua land, and at the Michigan and Red Cloud mines in northern Arkansas.

The main period of dolomitization was followed by the principal deposition of the metallic sulphides, the ores proper. These seem not to have been originally deposited in any regular sequence, either vertical or horizontal. Blende rests on galena and galena on blende indiscriminately, and both cover and are in turn covered by iron sulphide. Specimens from the Dead Mule mine near Joplin show galena resting on blende and again covered by blende. At Cave Springs blende is found on pyrite, and all possible relations between the three sulphides occur. Chalcopyrite is, usually at least, later than the main deposition of the other sulphides. A very common order is, first, blende, with a subordinate amount of galena and occasionally a little pyrite; second, crystals of calcite and pink dolomite in druses and channels running through the ore body; and, third, in these channels and on the dolomite especially, chalcopyrite. This may be seen at the Estrada and Mildred mines near Joplin, the Coleman and Buckeye mines at Aurora, and, in fact, throughout the Southwestern district. In certain cases galena and blende, as well as chalcopyrite, occur in these druses, but in many such cases at least their occurrence here seems to be due to the process of secondary enrichment.

The process of silicification, which in the Southwestern district took the form of deposition of secondary chert, was dominant later than the principal deposition of the ores. The chert forms a common matrix for the entire mass of material, and blende, galena, pyrite, and dolomite all maintain their form when in contact with it. This is possibly due in part to processes connected with the diffusion of material through solutions, which have already been discussed, but the field relations make clear that the main silicification took place relatively late in the general process. Specimens of chert showing on the under side the casts of dolomitic crystals are common, and were collected at Galena, at the J. F. Wilson mines near Joplin, at Aurora, and elsewhere. The distinction between this secondary or later chert and the original chert of the country rock has already been pointed out.

Macroscopic crystals of quartz are rather rare in the Southwestern district and occur only in druses of apparently recent formation. Good examples were observed on the Boston Get-There land. The quartz of the chert is microcrystalline.

It is important to get clearly in mind the original condition of the ore in order to be able to discriminate phenomena due to later changes. It is not easy in every case to make sure whether ores are in their original form or have been somewhat altered. Certain phenomena may be due either to original deposition or to secondary enrichment. For example, in dolomite- and calcite-lined water channels running through ore bodies apparently unaltered in any particular, notable amounts of galena and blende are often found. The Coleman mines at Aurora afford excellent examples of such occurrences. There is nothing to show that this galena and blende is not the result of secondary enrichment, and since such channels are not followed any great distance in mining operations it is not safe to assume that they have no connection with surface waters. In other cases, as in the sheet ore and the hard ground found in the mines of the Missouri Zinc Fields Company, there is no such doubt. The ores in the latter case are in thoroughly cemented ground. There are none of the phenomena of softening and disintegration with oxidation and carbonation of the materials such as accompany the action of surface waters. The ores in such a case represent doubtless the unmodified results of the first concentration. First, they show characteristically thorough cementation; second, they are associated with considerable quantities of dolomite, though in a nondolomitic country rock; third, while the bulk of the ore is blende, there is a subordinate but notable amount of galena in intimate admixture with the blende. In the Frounoy mine at Aurora pyrite is found with the blende in a similar situation. There is a total absence of all red clay or other evidences of oxidation in the original ore bodies and neither carbonates nor silicates are present, though secondary chert is the common matrix.

In the Kingfisher mine at Joplin the ore is seemingly due to the first concentration. It occurs in a broken flint, with some limestone and much bitumen. Galena and blende occur together, associated with some dolomite and calcite. The ores found in the Devono-Carboniferous shale by drilling at Granby show blende, galena, and pyrite in intimate admixture. These ores are at such depth and under such perfect cover that it is impossible to suppose they have been secondarily enriched; yet if the drill samples be a safe guide they show as much as 25 per cent of blende, and the latter is as notably dominant here as in any mine in the district.

It seems to be characteristic of the unaltered ore that it is in hard, thoroughly cemented ground. It usually occurs under a good roof, by which it has been protected from descending waters, and in mines having ores of this class the water pumped bears no relation to the amount of rainfall and evidently is derived from a deep-seated and widely connected circulation. It is also to be noted that in these ores the different sulphides occur together, and this without any evidence of rearrangement or bringing in of one or the other. This intimate mixture of the sulphides is believed to be an especially characteristic and significant point, and this belief is reenforced by observation in other fields. So far as the writer's experience goes, in unaltered and original bodies of sulphide ores the various sulphides occur, in most instances, intimately intermixed, though ores of the first or any later concentration may show crustification. Sulphides may also be mingled as a result of secondary enrichment, but it is usually possible to discriminate such a case. When the sulphides are found separately, either vertically or in areal distribution, and particularly in regions where several of them occur in definite order, their separation is reason for looking for secondary changes in the ore bodies. At the same time it is possible and even probable that in some instances sulphides are originally deposited separately. The reverse is believed none the less to be the rule.

ORES OF THE SECOND CONCENTRATION.

The ores of the second concentration, as that term is here used, have been largely derived from the ore bodies of the first concentration. It is possible, more particularly outside the Southwestern district, that certain of the ore bodies were formed from the disseminated minerals of the country rock by strictly surface agencies without the intervention of a deep-seated, wide-reaching earlier circulation of underground waters. Such ore bodies are believed, however, to be exceptional, and certainly in the Southwestern district, the one especially studied, they are unimportant. The larger number and the more characteristic ore bodies of the second concentration represent the reconcentration of earlier ore bodies. It is characteristic of these ore bodies that they are generally richer than those of the first concentration, and the process may accordingly be spoken of as one of enrichment. It is accompanied by mechanical and chemical changes in form, position, character, and richness of the ore bodies. It occurs in the belt of superficial alteration and is one of the phases of the general changes which take place in rocks at the surface of the earth. So far as these changes lead to the enrichment of ore bodies already present or to the formation of ore bodies in new situations they may be spoken of as (*a*) oxide enrichment and (*b*) sulphide enrichment. The former includes the changes common and characteristic above groundwater level in the belt of oxidation and the latter the peculiar enrichment of sulphide ore bodies which is found commonly at and for a short distance below that level. In literature the former class of ore bodies will generally be found discussed under the general title of gossan or iron hat, the miners' common terms for them. The general subject of the superficial alteration of ore bodies and the formation of the gossan have been excellently treated by Penrose.[1] He discusses in considerable detail the general process of residual accumulation and enrichment—the making of the ore body richer by the removal of the valueless gangue and country rock. He also discusses the chemical and physical changes which occur in the zone of superficial alteration in the ores themselves. It is proposed here merely to note the striking changes which have taken place in the ores of the region studied.

Oxide enrichment.—In the zone of weathering the most important mechanical effect is that of disintegration. The hard rock and the thoroughly cemented ore body become broken down into a soft, granular, and in some instances, sticky, muddy mass. The materials of the ore body are subject to ordinary processes of erosion and transportation, such as affect other rocks, and as a result ore may become scattered over the surface in small rounded masses and pieces. In such form it is known to miners as float mineral, and in the case of the association of ores here discussed, float mineral consists mainly of galena. Float mineral may be accumulated in crevices, cracks, or sink holes by purely mechanical means. This would be a case of mechanical concentration. By the disintegration and removal through solution of the associated rocks the ore would be left behind in a concentrated form; this may be spoken of as residual accumulation. The common gangue materials and the country rock of the Ozark region are notably more soluble than the ores, so that by simple residual accumulation many shallow surface deposits have been formed. Probably many of the smaller circle deposits of the Central region were formed by joint action of mechanical concentration and residual accumulation, and throughout the entire region residual accumulation has been a very important factor, as was shown by Winslow. Ore bodies formed by such strictly superficial agencies are practically limited in extent to the belt above ground-water level.

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[1] R. A. F. Penrose, jr.: Jour. Geol., Vol. II, p. 316.

The chemical effects of superficial alteration include the breaking down of the sulphides and the production of carbonates, silicates, and the rarer sulphates, chlorides, etc. The iron present in the ores and gangue material is largely oxidized to the ferric form, and this is the cause of the red color which so commonly marks ore deposits in the belt of weathering. Oxidation, carbonation, hydration, and solution are the dominant processes in this belt. One of the results of the process of solution is a frequent change in position of the ores and a common change in richness. Some of the ore is carried away in solution. Portions of it are redeposited in crevices or other openings where conditions are favorable. Other portions are carried below water level and redeposited in the ore body itself, producing a secondary enrichment, there taking the form of sulphide enrichment. Still other portions are carried off by surface waters to the sea.

The ore which is left above water level in the general migration of material downward resulting from erosion is usually considerably altered in composition. Such ores throughout the region consist usually of a matrix of red residual clay in which are found barite, galena, cerussite, smithsonite, hydrozincite, calamine, and the various iron oxides. There are subordinate amounts of pyromorphite, anglesite, leadhillite, and the simple and mixed sulphates, carbonates, etc., listed in an earlier portion of this paper. Galena is the only sulphide commonly found in quantity above water level. Blende, being much more easily oxidized than galena, rarely occurs in the belt of weathering. In the surface ore bodies, zinc most commonly takes the form of silicate in the Southwestern district and of carbonates in the others.

Silicate of zinc is particularly abundant in the Aurora, Mo., mines. Its characteristic occurrence is illustrated in some open pits near the Doddridge shaft on the Rinker land of the United Zinc Companies (fig. 23). These pits are roughly circular, and a particular pit examined was approximately 30 feet in diameter and 18 feet deep. The upper portion of the section exposed consisted of chert and residual clay. Below was a mud breccia with flint fragments. The latter were broken, softened, and much altered. Much of the chert had, indeed, become a soft, tallow clay which, while retaining the form and general appearance of chert, could be cut by a knife or rubbed to pieces between the fingers. It showed at least a final tendency toward dehydration, and in the process cracks opened and interior druses were formed. In the cracks and druses little plates of calamine occurred in intimate association with the cracked clay. The altered chert nodules were bedded in a reddish clay with masses of calamine and of blende altering to calamine exteriorly. The calamine shows in the latter case as a glistening surface material covering the blende and made up of bunches of minute, plate-like crystals. This material grades imperceptibly into the blende in such a way as to preclude the hypothesis of its being merely a later coating deposited over it.

The alteration of the sphalerite or blende to carbonates is shown best in the North Arkansas region, where it is a very common phenomenon. The kernels of unaltered sulphide surrounded by carbonate occur at most of the mines. There also has been in the region considerable transfer of material, as is shown in the development of mamillary and botryoidal coatings of clear carbonate over the other ores and accompanying rocks. Excellent examples of this are seen at the Morning Star mine, the Pierce mine, and others.

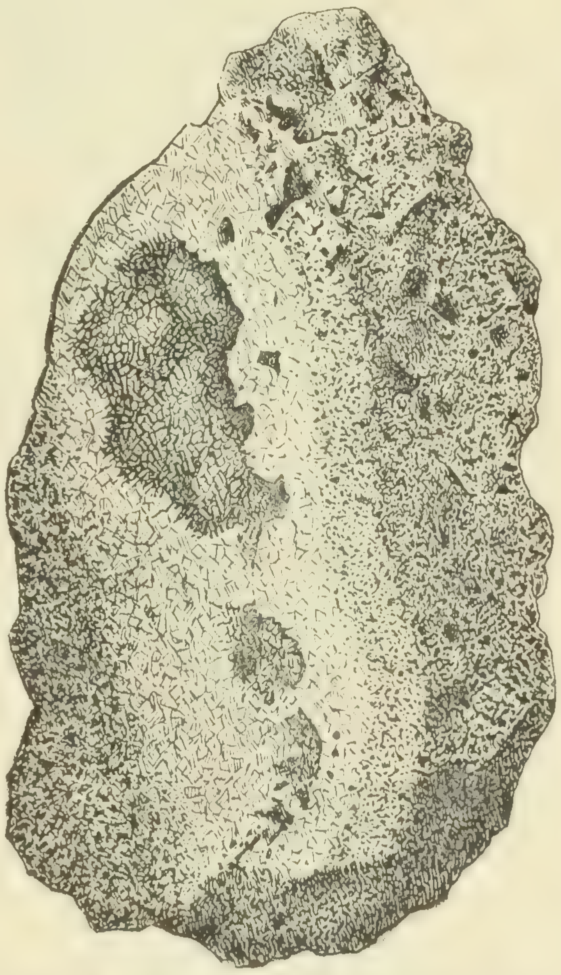

FIG. 23.—Zinc blende altering to calamine, Rinker land, Aurora, Mo.

The total effect of superficial alteration is the production of rich bodies of easily mined and easily reduced ores above water level. These bodies show a characteristic gangue and association of ores and may or may not be directly connected with deeper ore bodies due to other processes. Here, as in other districts, they are most abundantly developed on the slopes rather than in the deeper valleys or along the divides. This is due mainly to the fact that such a place is the common meeting point of waters passing through a hill and those coming down over its surface, but also to the opportunity for mechanical concentration along the base of a slope. So far as surface ores are directly connected with underlying ore bodies, their location in the valleys is due to the causes which have developed the valleys over the principal zones of fracture and crushing. This relation will be discussed later.

Sulphide enrichment.—One of the important processes by which ore bodies have become enriched has recently been much discussed under the general title of secondary enrichment.[1] Since the whole process of superficial alteration is in general result one of secondary enrichment, though often in specific cases one of depletion, it is thought better to discriminate the particular phenomena by using the term sulphide enrichment. The process is one phase of the general work of superficial alteration, but represents a particular portion of the general process which is locally of considerable importance. It causes the enrichment of the ore body at and below water level by the migration into and deposition within it of certain amounts of the ore bodies from the belt of weathering. In the Joplin area it differs in certain particulars from the process of reaction between the sulphides outlined by Weed and Emmons. In all these instances the reducing action is believed to be mainly the influence of one sulphide on the other, and the relative affinity of the metals for oxygen and for sulphur is very important. In the Joplin region the affinity for oxygen of the three metals, iron, zinc, and lead, is important, as usual, and they have gone into solution in the order named. In the presence, however, of an excess of organic reducing agencies all the sulphides seem to have been reduced with equal facility and without order. The sole exception is in the apparent lack of sulphur, which has limited the production of iron sulphide. In certain instances iron sulphide has formed; but this is not the rule for the district.

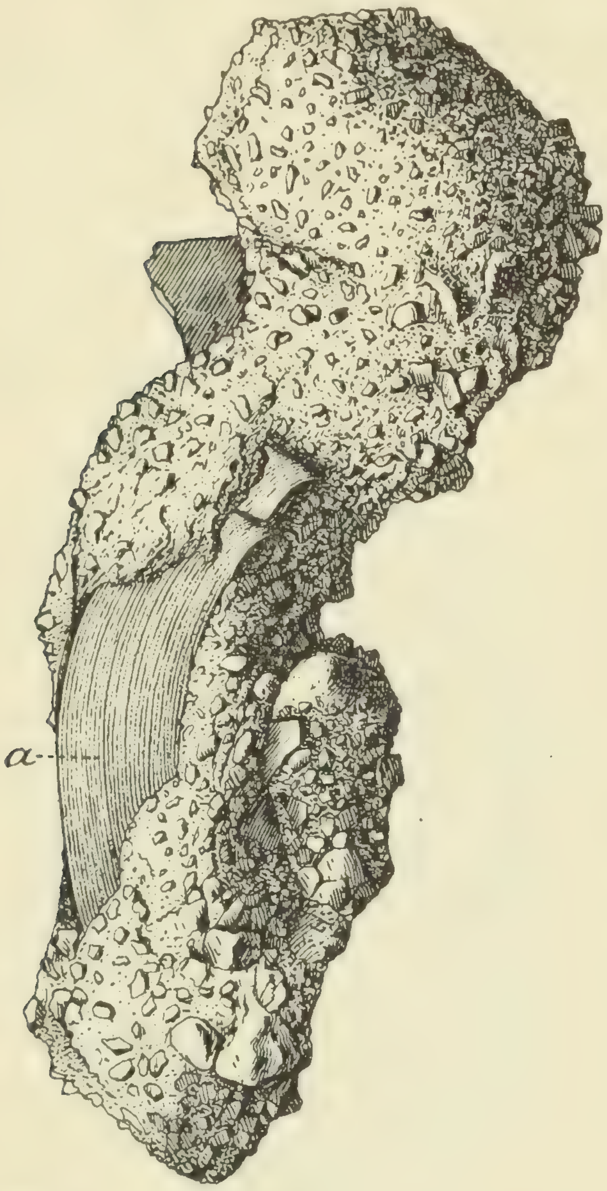

FIG. 24.—Influence of metallic iron in precipitating sulphides of zinc and lead, James River mines, Greene County, Mo. *a* Body of iron spike.

The influence as a reducing agent of metallic iron, artificially introduced since mining began, is shown in the specimens represented in figs. 24 and 25. They show recent deposition of blende and galena on each other and on certain iron spikes. They were obtained by Professor Shepard from a long-closed mine on James River, and are illustrated here through his courtesy. The blende is deposited on and clusters around the old spike in such form as to make clear that the iron influenced its deposition. It is not merely crusted over the iron, but shows no disposition to scale off as it might in case the relations were the result of purely cementing agencies. The galena crystals in turn show an equally close relation to the blende. This phenomenon is not quantitatively important in the district.

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[1] W. H. Weed: Trans. Am. Inst. Min. Eng., Vol. XXX, pp. 424–448; Bull. Geol. Soc. Am., Vol. XI, pp. 179–206. S. F. Emmons: Trans. Am. Inst. Min. Eng., Vol. XXX, pp. 177–216. C. R. Van Hise, Some principles, etc.: Trans. Am. Inst. Min. Eng., Vol. XXX, pp. 128–135.

Large bodies of blende at and for some distance below the ground-water level are very common throughout the region and are especially characteristic of the Southwestern district. The big zinc mines of the entire Southwestern district draw their supplies from a zone beginning at the level at which the ground water stood before pumping and extending irregularly downward. It is a truism here as in other districts that "jack makes in the water." This is due to several causes. Organic material is common in the limestone, the selvage, and the slate or shale "bars." The widespread presence of bitumen has been already emphasized. The ground water is one great reducing solution. It accordingly protects the ores from oxidation and the consequent change to the carbonates and silicates which characterize ores in the belt of weathering. It also serves to reduce any oxides or sulphates brought down to it by waters passing from the surface through the belt of weathering. There is thus an actual enrichment of ore bodies beginning at the water level and in this region extending as far below it in each case as the influence of surface waters can penetrate against the general upward movement of water due to hydrostatic pressure.

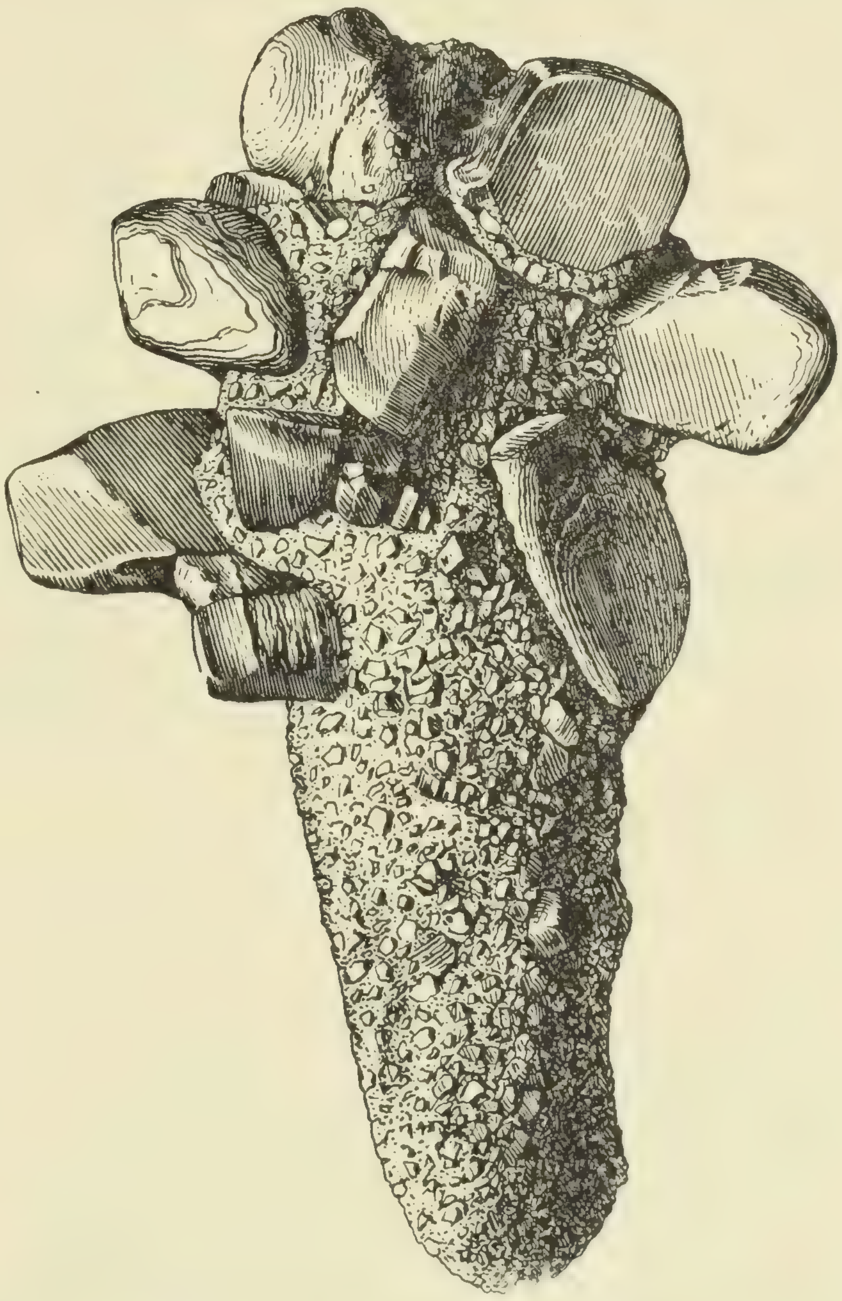


FIG. 25.—Influence of metallic iron in precipitating sulphides of zinc and lead, James River mines, Greene County, Mo.

There has been every opportunity for secondary enrichment of original ore bodies and production of practically new bodies of blende below water level. It has already been seen that in the original ore bodies blende greatly predominates over galena. It has also been stated that blende is more readily oxidized and more soluble than galena. The downward moving waters accordingly tend to carry the zinc from the belt of weathering into the horizon immediately below water level and to leave the lead behind. Thus the already notable predominance of blende in the original ores is increased. In instances ore carried down may be deposited in breccia alongside the original ore body or even at some distance from it, and thus may be produced an ore body showing a limited amount of galena in certain portions and nothing but blende elsewhere or one composed of blende only. While the ores of the first concentration show blende to be the dominant mineral for the district, it is probable that most of the big blende deposits have resulted from secondary enrichment. In certain cases the process of sulphide enrichment can be followed step by step. One of the most instructive cases is that shown on the Boston Get-There ground, to which attention was called by W. S. Hutchinson.

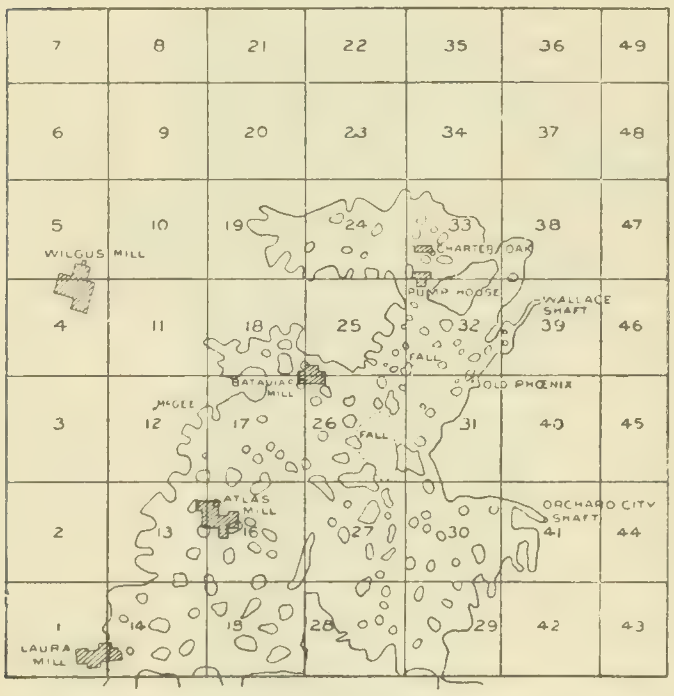
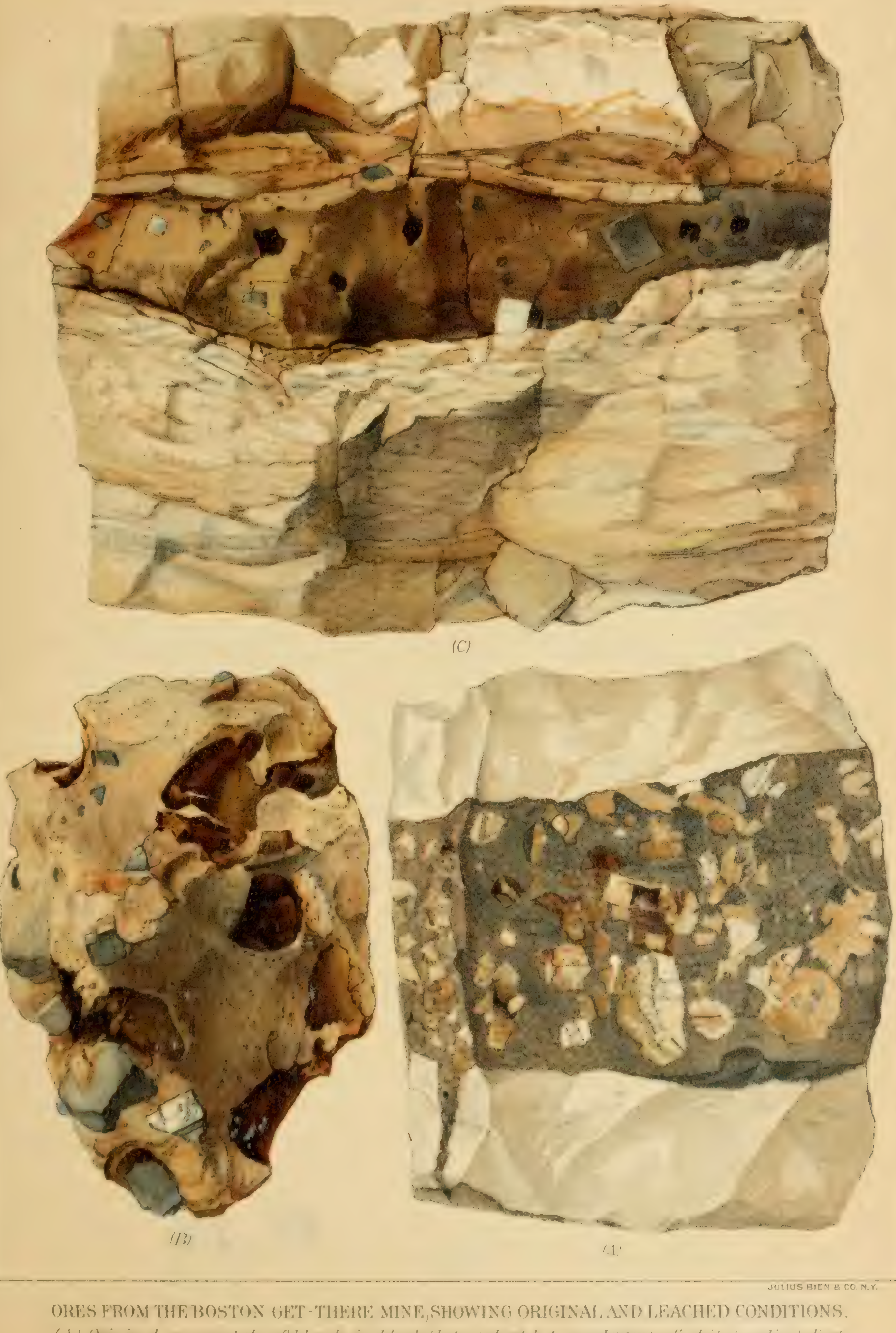


FIG. 26.—Ground plan of the Boston Get-There mines.

The Boston Get-There ground includes 40 acres located at Prosperity, near Cartersville, Mo. It lies on a very gentle swell, just east of a low, broad valley, extending northwest to Center Creek. This valley is full of important mines, many of which show rich ore in soft, broken ground.

A tongue of Coal Measures shale reaches down from a larger area to the northeast and forms a thin covering over the northeastern lots of the Boston Get-There ground. There is also apparently a minor amount of fracturing in this portion of the ground. In the northwestern portion there is a narrow, north-south belt of soft, broken, and disturbed ground, reaching down to at least the middle of the tract from north to south. In the northern continuation of this belt Coal Measures shales are found at a depth of 100 feet, and the evidence seems to warrant the belief that the belt referred to is one of fracturing and faulting. Over most of the tract the limestone forms the surface rock under the loose material of the soil. The beds have a very gentle dip to the southwest, as is shown by the flow of water underground. A plan of the underground workings of the mines is shown in fig. 26, and a general cross-section sketch from northeast to southwest is shown in fig. 27.

The mines are in typical sheet ground. The ores occur along bedding planes between the flint layers, below the heavy and here undisturbed limestone and flint. Immediately below the limestone is a layer of flint, from a few inches to 3 feet in thickness, which is of



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ORES FROM THE BOSTON GET-THERE MINE, SHOWING ORIGINAL AND LEACHED CONDITIONS.

(A) Original ore, crystals of blende in black (later) chert between layers of white (earlier) chert.
(B) and (C) Leached ore showing cavities left by the solution of blende.
Oxidation is indicated by the brown color of the chert.

open, porous texture and is known to the miners as "cotton flint." A partial analysis of this, made in the Survey laboratory by George Steiger, gave the following results: SiO_2, 76.96; CaO, 12.06. The cotton flint being more soluble on account of the lime in it, seems to have been originally the main horizon along which the waters moved. The normal ore of the area has been described already. To the north and east less blende, relatively, is found and more galena. That the blende was originally present and has been leached out is shown by the presence in the secondary flint of cavities having the outline of blende crystals (see Pl. XVI). Occasionally some of the galena has also been removed, as is proved by the presence of cube-shaped cavities. The iron has in part been removed, and in part oxidized to limonite. Some red clay is present, though not found elsewhere in the mines.

To the south and west small open cavities are found in the earlier ore, and in these, as well as in minor cracks, are clear, usually ruby-colored blende crystals, associated with cubes of galena and small rounded rhombohedrons of siderite, the iron carbonate. On both the galena and blende are small crystals of marcasite, and on the blende are little sphenoids of chalcopyrite, usually with uniform orientation. Greenockite also occurs as a greenish-yellow material dusted over the other minerals. Many of these features are illustrated in Pls. XVI and XVII.

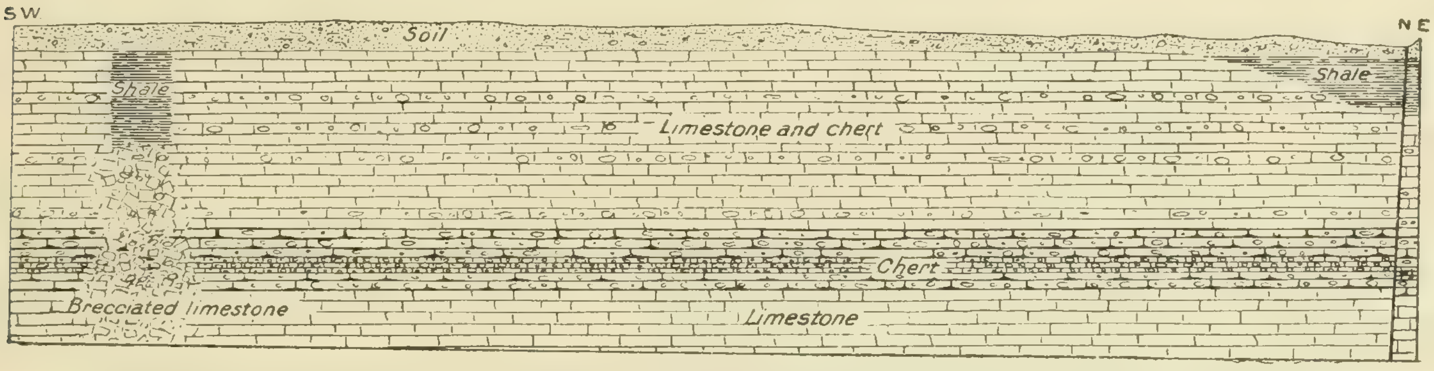

FIG. 27.—Cross section of the Boston Get-There mines from northeast to southwest.

A consideration of the relations of these ores makes it clear that there has been here solution of the ores in the northeastern portion of the ground and redeposition of them farther down the slope. It also seems clear that the waters active in this process were downward-flowing surface waters, and that the chemical reactions were essentially oxidation of sulphides to sulphates in the early portion of the waters' course and their redeposition, mainly as sulphides, in a later part of their journey. A probable shortage in sulphur is indicated from the deposition of part of the iron as carbonate.

VERTICAL DISTRIBUTION OF THE ORES.

The common law for zinc-lead deposits—that the larger and richer bodies of lead are found above the corresponding bodies of zinc—holds throughout the region. It is so universally true that it seems unnecessary to cite instances. The explanation of this phenomenon has been worked out by Van Hise.[1] It is that in the presence of downward-moving and oxidizing waters the sulphides of iron, zinc, and lead would go into solution in the order named, and that in the presence of reducing agents deposition normally would occur in the reverse order. The result would be a sorting out of the sulphides where they occur together, and a final vertical arrangement of iron, zinc, and lead sulphides, with the last on top. This is undoubtedly the explanation of the phenomenon. It is true also that waters moving in an upward direction charged with metallic sulphides and meeting descending oxidizing waters might readily be supposed to produce the same results, so that the arrangement is not necessarily altogether secondary. There is, however, little independent evidence favoring a belief in deposition in orderly arrangement by ascending waters, and in the mines and region most studied, at least, the phenomena are believed to be essentially due to secondary and modifying agencies.

Concentration by descending waters is usually most effective in sorting out the ores in regions where this downward movement is greatest—that is, in regions of great local differences in surface of the underground water.

In the Joplin region conditions are peculiar, in that the level of underground water has, so far as can be determined, stood for a long time near the surface. The region is one of slight relief, and it is believed that even at the present the major movement of the water is upward. Such downward movement as has occurred has taken place apparently against the general current of flow. This, coupled with the widespread presence of bitumen and other organic matter in the Joplin rocks, is probably the explanation of the comparative absence of products of oxidation and the nearness to the surface of the rich bodies of blende. The process outlined above explains the common occurrence of galena in the red surface clays overlying rich bodies of blende in unoxidized material.

The relative scarcity of iron pyrites in the region has already been noted. According to experience elsewhere there should be considerable bodies of mixed iron and zinc sulphides below the rich bodies of zinc ore, and at a still lower level the iron sulphide normally should become dominant. It is not impossible that this will prove generally true here, and at Granby the drill records show that it is true for a considerable area at least. The development up to the present indicates, however, that for the region in general, even in depth, the ore bodies will in most cases be found to be relatively free from iron.

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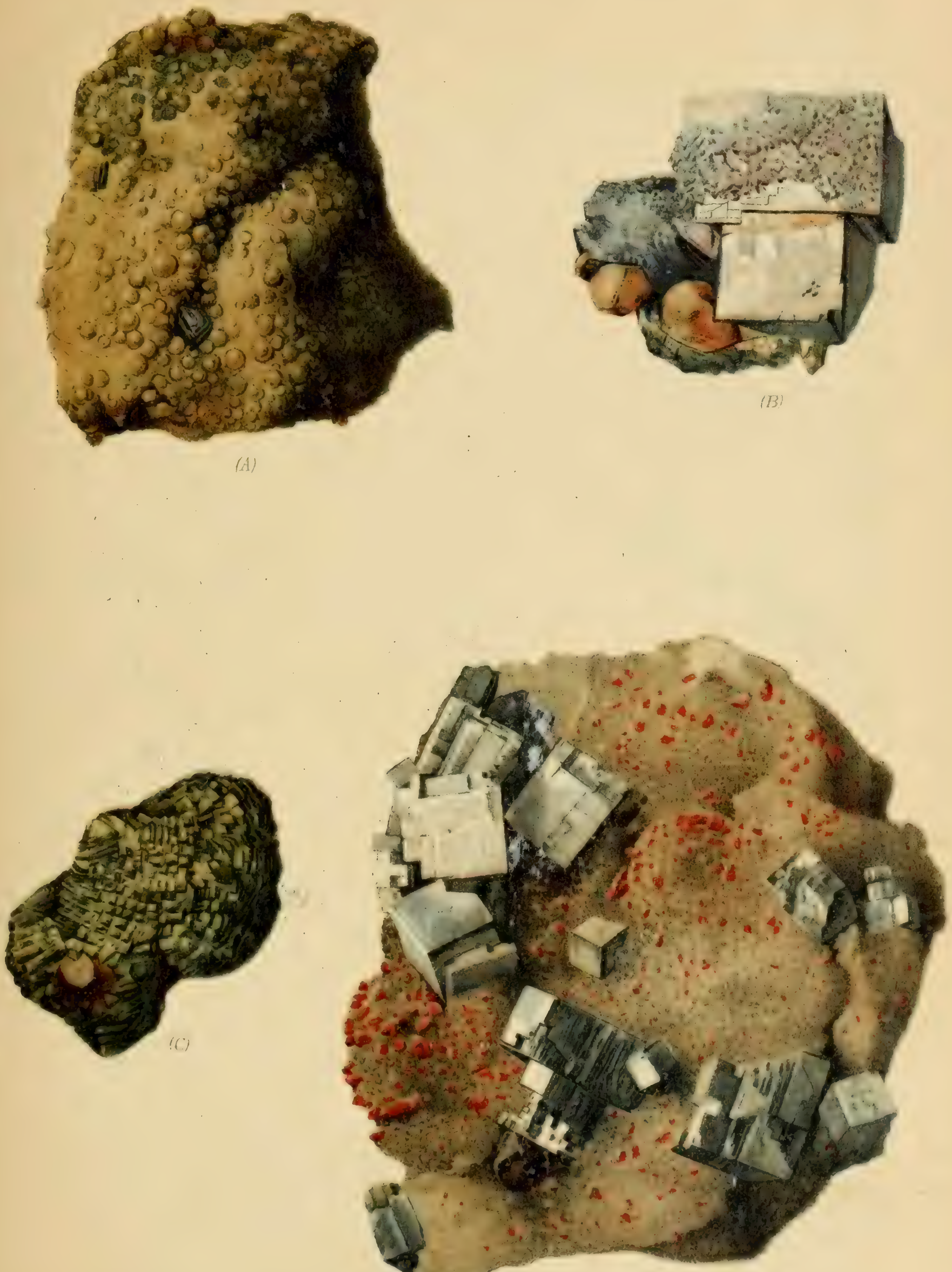
[1] Some Principles of Ore Deposition, p. 103.



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ORES FROM THE BOSTON GET-THERE MINE, SHOWING SECONDARY DEPOSITION OF SULPHIDES

(A) Rounded cubes of siderite secondarily deposited.

(B) Secondary blende and galena, the latter coated with marcasite.

(C) Blende covered with chalcopyrite crystals of uniform orientation.

(D) Secondary galena and blende.

CHAPTER VII.

By H. F. Bain.

GEOLOGY AND MINES DISCUSSED BY DISTRICTS.

The general geology of the Ozark region has been already discussed and summarized by Mr. Adams in Chapters II and III of this report. It remains only to emphasize those structural features which have been of importance in determining the form, position, and character of the ore bodies and to describe from among the mines visited those which best illustrate certain of these features. Especial attention will be devoted to the Southwestern district, since it was studied in most detail.

SOUTHWESTERN DISTRICT.

LIMITS.

The Southwestern district is of wide extent. Ores are found in it from Webster County, Mo., on the east, to Peoria, Ind. T., on the west, and from Dade County, Mo., on the north to Washington County, Ark., on the south. The area of occasional occurrences is even greater. The region of developed camps is more restricted. Within the general area outlined there is a notable tendency toward a grouping or bunching of the camps, and within the camps or subdistricts there is an even more notable clustering of the mines. The productive areas and mines are separated by relatively wide barren or undeveloped tracts. All of these productive belts seem to have been found early in the development of the district. The earliest maps show more or less prospecting at practically all the points where mining is now being carried on, and there has not been in recent years any notable additions to the list of mining camps, though there have been very remarkable increases in production and the limits of each camp are constantly being extended. Deeper drilling and closer prospecting are developing ore bodies in ground previously supposed to be barren, and with a better understanding of the structure and nature of the ore bodies it is to be expected that this will continue to occur.

GEOLOGICAL SECTION.

The ores of the Southwestern district are found mainly in the Carboniferous limestone. The district includes scattered mines in the area of the Cambro-Silurian, but it is the large deposits in the Carboniferous that are especially characteristic, and these will here be discussed. Outside the district the same limestones are not known to carry important amounts of ore. In these beds at Sedalia, Mo., limited amounts of galena, and in northern Arkansas both galena and blende, have been found. Future developments may show that in the latter district they carry important deposits, but for the present the mines in the Carboniferous limestones are confined to the Southwestern district.

The Mississippian as developed in this district consists of a lower, essentially shaly, and an upper, essentially limestone member. The lower member has been discussed under the name of the Devono-Carboniferous. It varies somewhat in lithologic character and in thickness, and these variations have been of considerable importance in controlling the deposition of the ore. In northwestern Arkansas, running up into McDonald and Barry counties in Missouri, the formation is a finely laminated, black, argillaceous shale of considerable thickness, being 70 feet thick at Bentonville and 50 feet at Sulphur Springs. The latter thickness represents the average for that region. The shale thins to the west, being usually 20 to 25 feet thick in Indian Territory. It also thins to the north, for at Roaring River, Barry County, Mo., it is 45 feet thick, and a few miles farther northeast it is 25 feet thick. Toward the north there is also a change in the character of the formation. It loses its black color, becomes ordinary blue argillaceous shale, and, taking on more lime, often changes into a shaly or thin-bedded limestone. This phase is seen at the mines at McDowell, in Barry County, Mo. When of this nature, the shale often has been overlooked in drill records, and reported as a part of the overlying beds. It always, however, remains more or less shaly. At Aurora, in drill hole 36, located on lot 95 of the Boston-Aurora ground, 10 feet of blue "slate" or shale was passed through between the depths of 270 and 280 feet. A corresponding shale was found in other drill holes put down by the same company. A drill hole put down by the Sphalerite Mining Company at the Nickel Plate mine, and on higher ground showed beds representing the same formation between depths of 360 and 389 feet. At Springfield 30 feet of shale occurs between depths of 250 and 280 feet, in the well at the electric-motor plant. In the Carthage deep well the rock is reported as a shaly limestone 30 feet thick between 350 and 380 feet in depth. The Brewery well at Joplin shows 40 feet of clayey limestone beginning at a depth of 315 feet. At Oronogo corresponding beds were found at a depth of 350 feet and continued to 390. At Granby several drill holes in the NE. ¼ of the SW. ¼ of sec. 31, T. 26 N., R. 30 W., show the shale between depths of 279 and 299 feet. In other holes in the vicinity it is found at 305 to 325 feet in depth. The variation in depth of this shale is due in part to surface inequalities and in part to displacement of the shale by faulting. The natural exposures of the region confirm the evidences of the drill holes that the Devono-Carboniferous in the ore-producing regions has less than the normal thickness, and is less shaly than usual.

The Devono-Carboniferous was laid down after a long period of erosion in which the area was reduced essentially to an even plain. The evidence of general unconformity is distinct, but marked local irregularities at the plane of contact do not often occur. Where such irregularities are known they are the result of faulting.

The limestone member of the Mississippian as developed in the region includes the beds which in Arkansas have been referred to as the Boone chert, and the term Boone formation will be used here. The Boone as developed in the Southwestern district includes an upper and a lower member, which have been separately mapped by Shepard in Greene County, and which may be readily recognized in the field. In drill holes their separation is not always easy, and for the present no attempt will be made to distinguish them except in a general way. The revision of the nomenclature is purposely left until the detailed mapping shall have been carried further. Of the two divisions of the Boone the upper is the more important, as it forms the country rock throughout the mining region. In character it is so variable that up to the present it has been impossible to make a general section which could be recognized over any wide area. Locally, a certain sequence is sometimes noticeable. At Carthage there are certain heavy-bedded limestones which seem to represent the upper portion of the formation. Their character is shown in the quarries north of the river and near the St. Louis and San Francisco Railway station. In the latter quarry the following section was measured:

Section at Carthage, Mo.

	Feet.
7. Limestone, badly weathered, much cut by water courses, showing coarse granular surfaces with rounded surfaces characteristic of solution	4
6. Limestone, gray, crystalline, interbedded with thin chert bands	6
5. Limestone, coarse-bedded, gray, crystalline, horizontal bands of styolites and with *Deltodus occidentalis* at upper surface	7
4. Chert	$\frac{1}{6}$
3. Limestone, gray, as above	5
2. Limestone, gray, *Deltodus* on upper surfacer	4
1. Chert and cherty limestone	3

The chert, No. 1 of the section, is a well-defined bed and may be traced a half mile or more to the west, and has been recognized in drill holes in the quarries on the north side of Spring River.

Below the quarry beds, as seen at Carthage, there is commonly a thickness of 150 to 180 feet of interbanded limestone and chert, as shown in the Boston Get-There section, already given, and in numerous drill holes on the Missouri Zinc Fields Company's land and elsewhere. It is this portion of the section which is most generally seen in mine sections. Below it, in the Cartersville-Prosperity and the Oronogo areas, is very commonly a thick bed of massive chert, and a similar bed is encountered in the mines of Tanyard Hollow and Galena. There are exposures along Shoal Creek at Grand Falls, Redding's mill, and elsewhere, which show a very thick body of chert quite free from limestone. It has not been possible to show that these chert beds represent one stratigraphic horizon. The distribution of the chert is somewhat irregular, as has been emphasized by Winslow[1] and Haworth.[2] To some extent at least the irregularities are due to changes in dip and to faulting rather than to lack of continuity of the chert. For example, opposite Redding's mill the chert which appears to be absent is really present. This is shown by a recently developed mine in which the ore is found in the top of the chert. The latter lies below the level of the river bottom, and has thus escaped observation. As has already been shown the chert acts, locally at least, as a bed rock against which the ores have been concentrated, but whether it may be expected to perform a similar function over any considerable portion of the district is as yet uncertain.

Below the heavy chert and above the Devono-Carboniferous there is a somewhat variable thickness, ordinarily of 75 to 150 feet, of interbedded limestone and chert. Whether this belongs entirely to the lower member of the Boone or in part to the upper member is as yet undetermined. The total thickness of the Boone formation in the Joplin region ranges from 300 to 350 feet. In exceptional cases, as a result of faulting, the base is found at less or greater depth from the surface.

GENERAL STRUCTURE.

The essential structure of the Southwestern district is shown in fig. 28, representing a cross section from Cedar Gap through Carthage and Joplin to the Upper Carboniferous beds west of Spring River. The strata along the line of this section have a gentle dip to the west, which coincides essentially with the slope of the surface. The upper portion of the Boone formation is accordingly exposed over the surface for the entire distance, except where erosion has cut into it. To the west, above the limestone and chert, are the shales and sandstones of the Coal Measures, and the various outliers indicate their former extension over the area to the east. These upper shales are to all intents and purposes impervious, and in the area covered by them they separate the surface waters from those entering the limestones along the outcrop of the latter. At an earlier time, when the shales covered more of the area, they were more effective in this particular.

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[1] Loc. cit., Vol. VII, pp. 416-417.

[2] Bull. Geol. Soc. America, Vol. XI, pp. 231-240.

Below the limestones of the Boone formation is the Devono-Carboniferous shale, forming a practically continuous stratum. It cuts off the circulation in the limestones above from that in the Cambro-Silurian beds below. Still lower than the Cambro-Silurian beds are the pre-Cambrian crystallines, which very largely limit the downward circulation of the waters below the Devono-Carboniferous. The difference in elevation between Cedar Gap and Joplin is 700 feet in round numbers, and accordingly water entering the strata at Cedar Gap and not finding its way to the surface before reaching Joplin is under a hydrostatic pressure of approximately 34 pounds to the square inch, less the loss due to friction against the walls of the conduit through which it has traveled. It should, therefore, at the latter place have a general upward movement and should tend to flow out at the surface from deep wells. In the Redell deep well at Joplin water rises from a depth of 1,350 feet to within 80 feet of the surface, and is not lowered when pumped at a rate of 90 gallons a minute. At Carthage it rises to within 15 feet and seems inexhaustible. In a number of holes put down in the region this deeper water is tapped. It is encountered at very irregular depths in the Cambro-Silurian, and at present no definite water-bearing beds can be made out in these strata. These facts seem to indicate that the main flow is along fractures in the limestones rather than through thick and continuous sandstones, as is the usual case in artesian wells. In the early days of mining the ground water stood very near the surface and the large amount of water to be handled was one of the serious problems of mining. Even yet when mines are opened in new territory pumping is a serious tax on the enterprise. The water level in the Redell well, which now stands at 80 feet, is probably held down to that level by the general pumping and the loss of head due to springs. Throughout the entire district there are numerous cracks and crevices which cut down through the impervious Devono-Carboniferous shale and relieve the

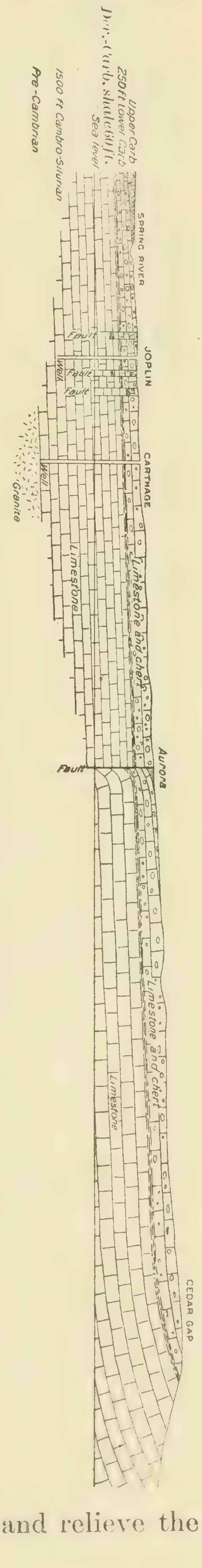

FIG. 28.—Section from Cedar Gap westward through Joplin.

hydrostatic pressure. The outflow expresses itself in the numerous large springs which are so characteristic of the region, and are instanced in such geographic names as Spring River and Cave Spring. The presence of such fractures is also suggested by the form, and more particularly by the distribution of many of the valleys. These are characteristically long, narrow, shallow, closely spaced, and parallel. The streams are very largely fed by springs, and in connection with the general phenomena of the region the inference is warranted that the ultimate source of the springs is very deep. The best reason for believing that the ground water is fed mainly from distant sources lies in the fact that the amount of water pumped from the mines is independent of seasonal changes. Except in the case of unprotected openings or very open ground, severe storms and rainy weather do not increase the amount of water that must be handled.

FAULTING.

The presence of deep fractures in the Joplin region is shown by faults of 100 to 150 feet or more. Where strata are displaced this much it is a fair inference that the fracturing extends at least 200 feet deeper, hence across the Devono-Carboniferous shale, which is found at depths of 300 to 350 feet. These faults and their relations to the ore deposits have not heretofore been properly appreciated, though they were noted by Jenney,[1] Shepard,[2] and Blake.[3] In a series of beds such as the limestones and cherts of the Joplin area, where one portion of the section is lithologically like so many other portions, faults may be present and yet may remain unrecognized. It is only where a fault occurs in two or more beds of different character that it is possible, in the absence of extremely detailed work, to measure the displacement. Even in such a case, if there be a marked erosion unconformity between the beds, mere juxtaposition at various levels is not in itself sufficient proof of faulting. In this district the faulting is made clear by the relations of the overlying Coal Measures shales and sandstones to the limestones and cherts of the Boone formation. These relations are, however, obscured by unconformity between these beds and by the influence of downward settling as a result of solution. Such faulting as has been recognized in the region has so far been usually referred to the latter cause,[4] but this explanation can not be deemed adequate.

Very clear instances of faulting were observed at many points in the district in the course of the present work. Several of these have been already described. At Aurora the faults and their relations to the ore bodies are shown on the accompanying map (Pl. XVIII).

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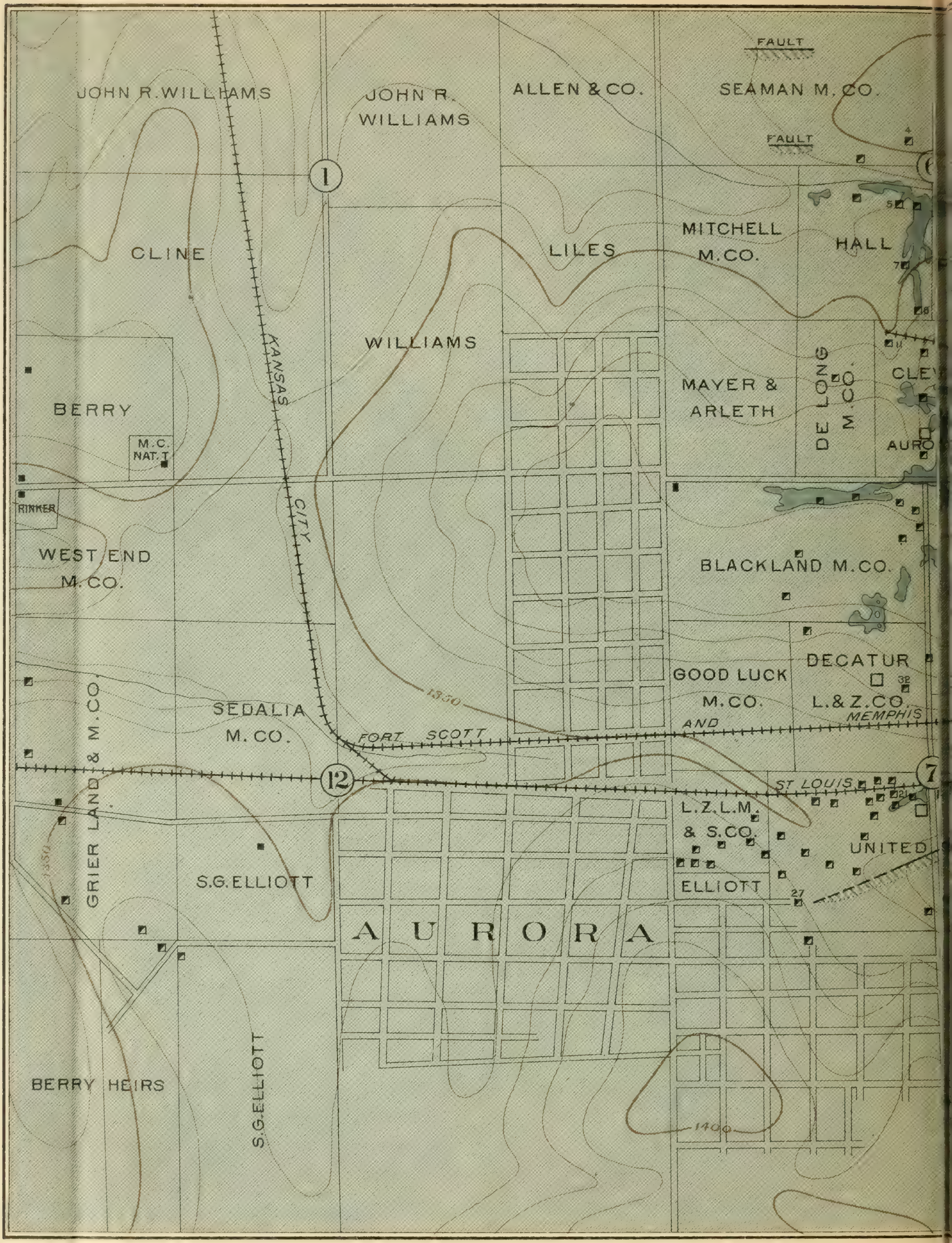
[1] Lead and zinc deposits of the Mississippi Valley: Trans. Am. Inst. Min. Eng., Vol. XXII, p. 14..

[2] Missouri Geol. Survey, Vol. XII, Pt. I, p. 172.

[3] Trans. Am. Inst. Min. Eng., Vol. XXII, p. 621 et seq.

[4] Winslow: Missouri Geol. Survey, Vol. VII, 1894, p. 480.

U. S. GEOLOGICAL SURVEY



PRELIMINARY MAP OF THE AU

Topography by Basil Duke, G

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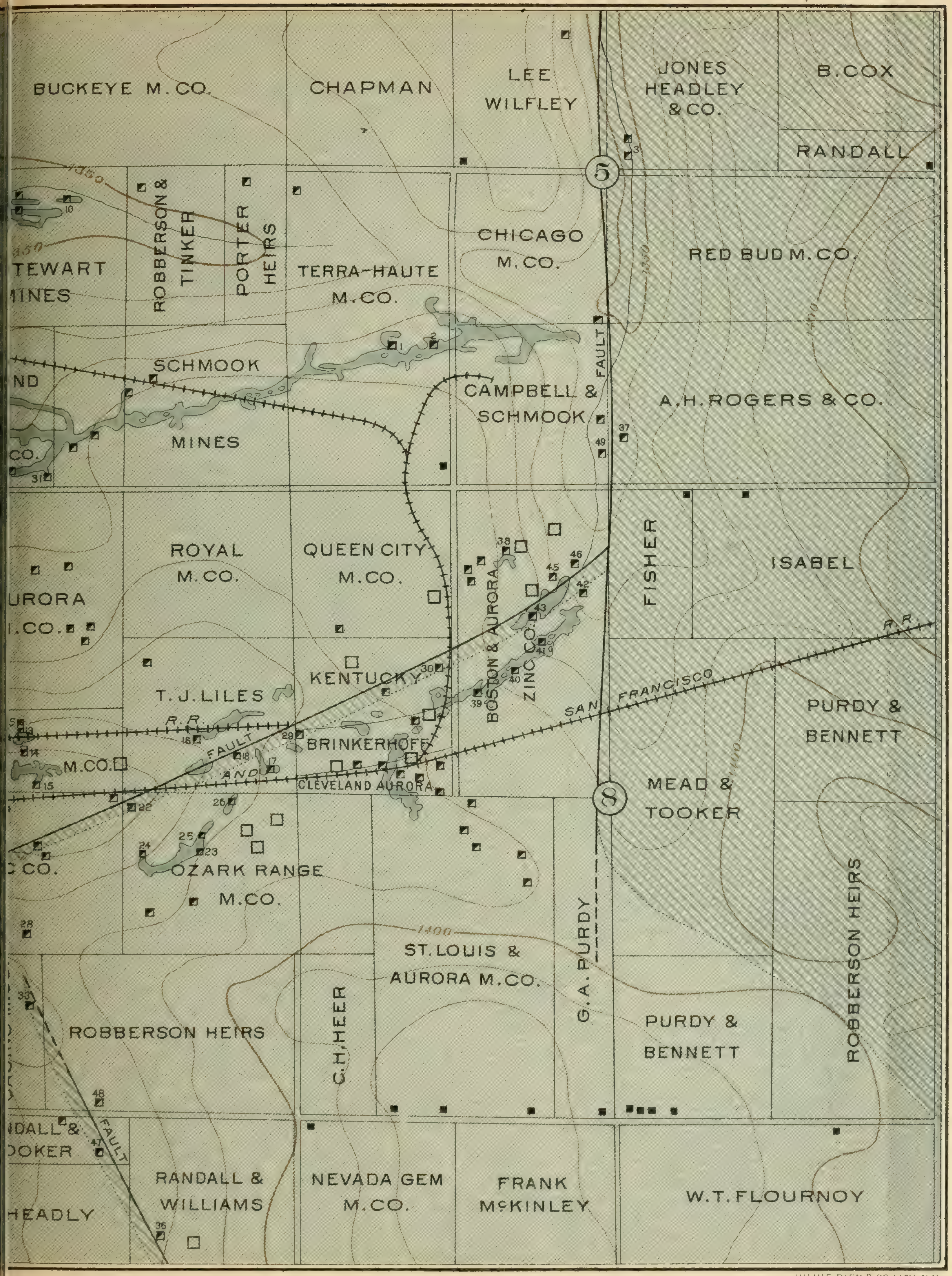
Contour int

LEG

LOWER CARBONIFEROUS UPPER CARBONIFEROU



JULIUS BIEN & CO. LITH N.Y.

PARTIAL LIST OF MINES

1 SASSAFRAS
2 ORIENTAL
3 BOWYER
4 FLYING DUTCHMAN
5 CHRISTIAN
6 DOG
7 PUP
8 BAPTIST
9 FIRST METHODIST
10 CONGREGATIONALIST
11 VALLEY QUEEN
12 BALDWIN
13 JACK RABBIT
14 COTTONTAIL
15 MADISON
16 BIG SIXTEEN
17 LITTLE BETSEY
18 OLD BETSEY
19 WILSON
20 DEWEY
21 BUCKEYE
22 INDIANA
23 WORLDS HERALD
24 HAYS CITY
25 MINT
26 WORLDS FAIR
27 SECOND NATIONAL
28 COLEMAN
29 NICKEL PLATE
30 JUMBO
31 PERSIMMON
32 DAISY BELL
33 SYCAMORE
34 MAYFLOWER
35 JOHN BULL
36 FLOURNOY
37 RODGERS
38 ARGYLE
39 BOSTON AURORA NO
40 " " "
41 " " "
42 " " OL
43 " " NO
44 " "
45 " " NE
46 MYRTLE J.
47
48
49 WHEAT AND HOY

RA MINING CAMP, MISSOURI

ogy by George I. Adams

½ ¾ 1 MILE

. 10 feet

D

The general country rock at Aurora is the usual interbanded chert and limestone, as may be seen in any of the shafts which have been sunk in the hard or "bar" ground. Such are the Myrtle J., No. 5 and No. 6 of the Boston-Aurora, the Louise, the World-Herald, the Ozark, and many others. The ores are developed in breccias at various horizons in this sheeted rock, usually in rather definite and persistent runs. Some of these runs certainly follow fault lines, and the others probably do.

In the eastern portion of the territory covered by the special Aurora map there is an area known as Sand Ridge, composed of Coal Measures shale and sandstone. This extends in a long, narrow belt across the country, as may be seen by the general map. Its eastern limit is not shown on the detailed map. This border is irregular and shows definite relations to the topography. It is made by the thinning out of the beds. The western border, across the area of the special map, is direct and sharp cut and is the result of faulting. Along the eastern edge of the area there outcrops a coarse conglomerate which is covered to the west by argillaceous black shale and a gray micaceous sandstone. Along the western border this conglomerate does not outcrop, but the upper beds are brought into sharp contact with the ordinary chert and limestone. In sinking the Bowyer shaft the following section was encountered:

Section at the Bowyer shaft.

	Thickness.	Depth.
	Feet.	*Feet.*
4. Gray, micaceous sandstone and soft, argillaceous shale	127	127
3. Conglomerate, with rounded chert pebbles, in a red calcareous matrix	5	132
2. Limestone and chert interbanded	25	157
1. Brecciated chert and limestone	43	200

The ore body is developed in the chert and limestone from 157 feet in depth down to 200 feet. The structure here is represented in fig. 29, drawn to natural scale. The section shows a normal fault of at least 130 feet, with the downthrow to the east. Mr. Adams and Mr. Burchard have carefully traced this fault to the south along the course shown on the map, to the point where it leaves the Coal Measures and becomes unrecognizable. It is impossible to suppose that the Coal Measures and the limestone are merely brought into contact as a result of the pre-Coal Measures erosion. That there was a basin filled with Coal Measures, lying in the limestone, is not improbable, but there clearly is a fault along the western edge. The finding of the conglomerate at the base of the Coal Measures along the eastern outcrop and in the shaft, but not along the western limit of the area, precludes the simple basin hypothesis. The abrupt contact and its generally direct course afford supporting evidence. Indeed, a straight contact of this type, passing across the country without any relations to the topography, is incompatible with any explanation other than that of faulting. It is also in harmony with this interpretation that the amount of water at first pumped from these shafts, approximately 2,000 gallons a minute, was exceptional, and that the flow is even now very heavy. This water does not seem to come mainly, as might perhaps be expected, from the softer Coal Measures and the contact between them and the limestone, but comes up from the limestone. At a depth of 170 feet the inflow of water from the small channels in the chert was very marked. There is practically no evidence of oxidation or the action of surface waters in the ore body. The ore body itself is firmly cemented and has all those peculiarities which have been pointed out as especially characteristic of a primary or first concentration. These phenomena indicate connection with the deeper circulation and evidence the depth of the faulting.

Another excellent illustration of faulting in the Aurora region is the displacement running from the Myrtle J. southwest to the Second National. This fault was also traced out on the surface by Mr. Adams and Mr. Burchard. It is well exhibited in several mines, and is seen also in open pits at several points. It is a block fault, a narrow belt of Coal Measures shales, 60 to 80 feet wide, having been dropped 80 to 90 feet. The limestone on either side is not known to be displaced, though it is difficult to make sure as to this. The fault was seen in shaft New No. 6 of the Boston-Aurora, where, at a depth of 70 feet, a horizontal drift driven to the south cut into the shale. At the contact both the shale and the chert were much disturbed. Sharp-angled blocks of chert and limestone were found in the shale, and portions of the latter were squeezed into the fractured chert and limestone. Pieces of the shale itself, with the bedding planes at high angles, occurred in the main body of the shale near the contact. The phenomena are clearly those of faulting. The workings in shaft No. 5 extend under the fault block and ore was found on both sides and below it. The shale is cut into at several points along the course of the fault and in some open pits between the two shafts of the Big Sixteen mine Coal Measures sandstone may be seen in contact with the ordinary limestone of the region, with brecciation and drag phenomena at the contact.

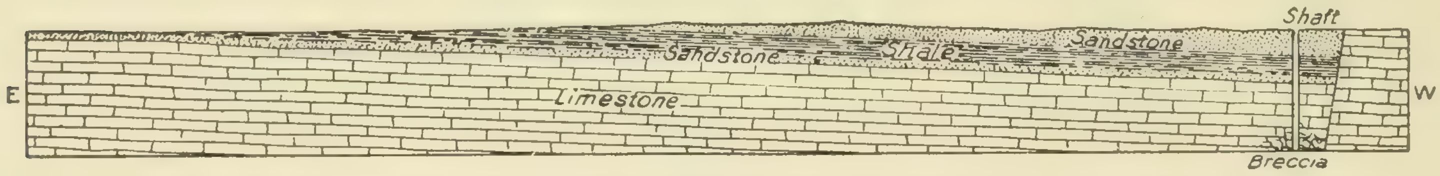
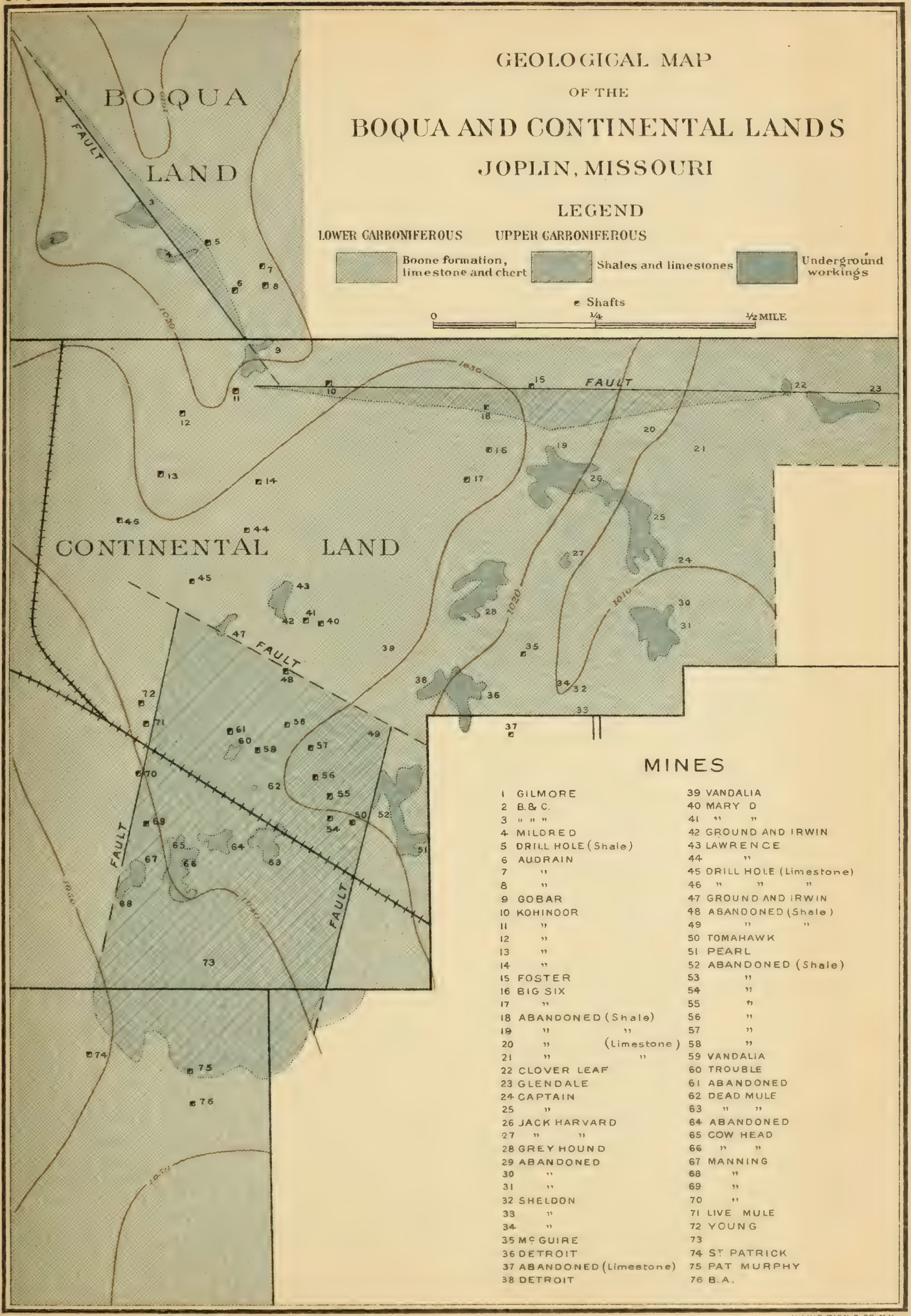


FIG. 29.—Cross section of the Sand Ridge fault at Bowyer mine, Aurora, Mo.



GEOLOGICAL MAP
OF THE
BOQUA AND CONTINENTAL LANDS
JOPLIN, MISSOURI

LEGEND

LOWER CARBONIFEROUS UPPER CARBONIFEROUS

▨ Boone formation, limestone and chert
▨ Shales and limestones
▨ Underground workings
▪ Shafts

MINES

1	GILMORE
2	B. & C.
3	" " "
4	MILDRED
5	DRILL HOLE (Shale)
6	AUDRAIN
7	"
8	"
9	GOBAR
10	KOHINOOR
11	"
12	"
13	"
14	"
15	FOSTER
16	BIG SIX
17	"
18	ABANDONED (Shale)
19	" "
20	" (Limestone)
21	" "
22	CLOVER LEAF
23	GLENDALE
24	CAPTAIN
25	"
26	JACK HARVARD
27	" "
28	GREY HOUND
29	ABANDONED
30	"
31	"
32	SHELDON
33	"
34	"
35	Mc GUIRE
36	DETROIT
37	ABANDONED (Limestone)
38	DETROIT
39	VANDALIA
40	MARY D
41	" "
42	GROUND AND IRWIN
43	LAWRENCE
44	"
45	DRILL HOLE (Limestone)
46	" " "
47	GROUND AND IRWIN
48	ABANDONED (Shale)
49	" "
50	TOMAHAWK
51	PEARL
52	ABANDONED (Shale)
53	"
54	"
55	"
56	"
57	"
58	"
59	VANDALIA
60	TROUBLE
61	ABANDONED
62	DEAD MULE
63	" "
64	ABANDONED
65	COW HEAD
66	" "
67	MANNING
68	"
69	"
70	"
71	LIVE MULE
72	YOUNG
73	
74	ST PATRICK
75	PAT MURPHY
76	B. A.

JULIUS BIEN & CO. N.Y.

Farther southwest the fault may be traced by drill holes and mine shafts which penetrate shale instead of the customary limestone.

On the special map of the Boqua and Continental tracts, Pl. XIX, the more prominent faults present are represented. The Continental tract lies west of the city of Joplin and at one time belonged to the Empire Zinc Company, when it was known as the Kohinoor land. It has long been a steadily producing area. The more important underground workings are represented upon the map, though the data are not complete in this regard. Of the faults recognized, perhaps the one crossing the Boqua land and running southeast to the Gobar or Two Johns mine on the Continental is the best displayed. This was examined in the Mildred mine.

The Mildred shaft is 120 feet deep, and is in hard, horizontally bedded limestone and chert. A drift from the bottom of the shaft to the east passed into Coal Measures shale at a distance of 40 feet from the shaft, and continued in that material approximately 40 feet farther. At the contact of the shale and the limestone there is an evident fault with a hade to the east. There is not a single contact plane, but a belt of about 20 feet of broken and disturbed strata, consisting mainly of black shale containing angular blocks of chert and limestone. Calcite and gray dolomite fill in the crevices in the mass. The larger bodies of chert pitch with the hade of the fault, and the bedding planes of the shale show the same pitch and at times are even vertical. The gray dolomite is usually developed around the chert blocks. The materials show very evident disturbance, and the softer shaly material is squeezed and crowded in between the blocks of chert and limestone in a manner possible only as a result of pressure. Along the contact and in the shale there is much breccia. It consists mainly of fragments of chert recemented by gray dolomite, but includes also broken pieces of limestone. The interstices and druses show pink dolomite and blende. Along the bottom of the drift the rocks are more nearly horizontal and less disturbed and consist mainly of limestone and chert. This indicates that the drift is driven about at the base of the shale.

In the B. & C. mine the shale was again encountered in the head of a drift driven to the southeast. This would give the fault the course of about N. 25° W., which brings it near the Gilmore mine, where good ore bodies occur, and indicates a probable connection with the broken ground of the I Know mine to the north. To the south the fault cuts the Gobar or Two Johns mine, where it is evident in a body of rich ore-bearing breccia developed along the west side of a hard limestone bar or wall. This fault illustrates well the fact that only along a portion of its course are the overlying shales brought down into contact with the limestones so as to make the disturbance evident. In the Gobar mine the east wall is a hard limestone.

North of the Gobar the Audrain mines are also in hard limestone. In the Mildred and B. & C. mines the shale is cut into, in the latter at a depth of 170 feet, and in a drill hole some distance east of the Mildred the shale was also encountered. Brecciation is common all along the fault, and ore bodies, especially on the southwest side, are not infrequent. The disturbance evidently marks a zone or belt of fracturing, involving the downthrow of an irregular linear block of strata and the subsequent development of shattering and pressure phenomena.

From south of the Gobar a second fault line may be traced east by the occurrence at considerable depths of Coal Measures shales with the hard limestone on either side. As in the case just described, the shale belt seems to be somewhat irregular. The fault was examined only in the Glendale mine. As seen here there is an overthrust, the shale being thrown up over the limestone. The ore is developed largely along the contact. In the Glendale, and again in the Clover Leaf to the west, there is evidence of brecciation and disturbance along the fault plane (see fig. 30).

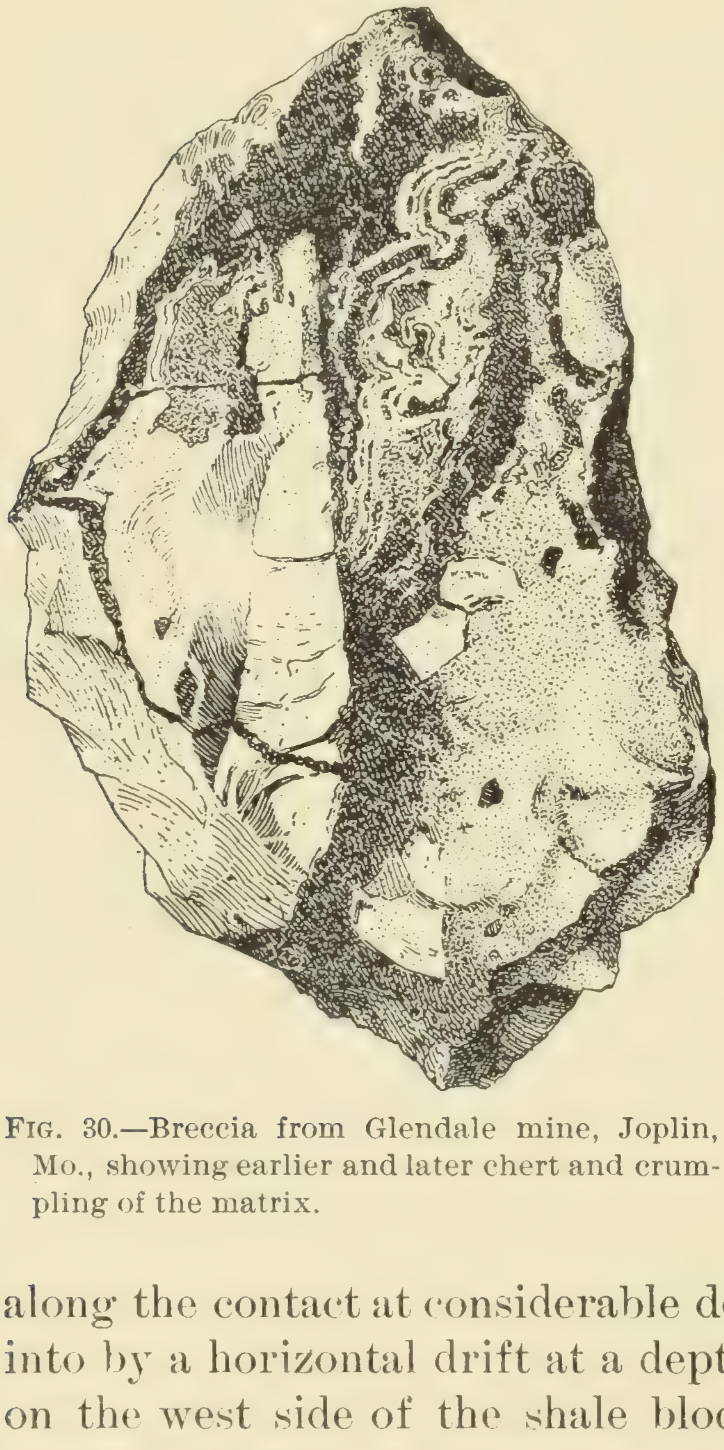


FIG. 30.—Breccia from Glendale mine, Joplin, Mo., showing earlier and later chert and crumpling of the matrix.

On the southern portion of the Continental tract there is a large block of Coal Measures shales faulted down into the limestone. The fault on the east side of this block may be seen in the Pearl mine. Its course is shown on the map. This fault is, as usual, made evident by the juxtaposition at the same level of shale and limestone, with marked disturbance along the contact at considerable depth. In this case the shale was cut into by a horizontal drift at a depth of 136 feet. The fault indicated on the west side of the shale block was seen in the Manning mine at a depth of 145 feet, where the shales dip away from the contact at an angle of 14°. It is impossible to suppose that the shale was deposited at this angle, and the only alternative hypothesis is that of disturbance since deposition. The shale bar is said to have been struck again, 200 feet southwest of the shaft, at a depth of 160 feet. The fault along the north side of this block was not seen in any workings and is merely inferred from the distribution of the shale.

Within the area covered by the block of shale, marked off by the bounding faults, there are numerous minor displacements and cross faults. Two of these were examined in the Trouble and Manning mines. Their influence is to modify the general effect of the faulting and to make very uneven the plane of contact between the shale and the underlying limestone. The general result of the faulting seems to have been the displacement of a block of shale having its greatest downthrow to the northeast. To the south the amount of shale penetrated in the various shafts becomes less and less until, in the St. Patrick and the B. A., no shale at all is found. Along the west side of the fault block a narrow strip of shale seems to have dropped down to a greater depth than would be expected from the general structure. This is indicated by the depth at which the shale is found in the Manning mine.

The special maps of the Aurora camp and the Continental tract probably do not show in either case all the faults present. Certainly they do not show all the fracture planes and lines of disturbance. Nevertheless they do indicate the main lines of faulting and displacements which are easily recognized.

BRECCIATION.

One of the most important and most significant features of the Southwestern district is the amount of brecciation which has taken place. A very large majority of the mines obtain the bulk of their ore from breccias. These breccias have already been described. Something of their extent may be inferred from the fact that the John Jackson mine has been worked for a distance of 830 feet, with a general height of stope of 40 to 60 feet and a usual width of 50 to 60 feet. In places the ore body is 125 feet wide. The bottom of the drift shows ore-bearing breccia, and the horizontal limits of the ore body are not yet determined. This ore body is in hard, thoroughly cemented ground. It is impossible to refer the origin of the breccia to any secondary settling or to the action of surface waters in softening the rock. The mine is covered by a thick bed of undisturbed rock and no red clay is found in the mine except at one point where, in mining, the overburden was cut through. To the south the breccia is cut off by a clean, sharp wall of horizontally bedded and undisturbed chert and limestone. Along this wall and in the ore body are occasional sharp planes of fracture, and in the breccia proper there is, as is common in these breccias, clear evidence of movement between the individual particles of chert, followed by recementation. Brecciation was evidently accomplished by a series of movements extending over some little time, with intervals during which the process of cementation was active. The particles of older chert are sharp angled and splintery and show abundant evidence of having been crushed. The same phenomenon is seen in an interesting breccia in the B. & C. mine, on the Boqua land. It is developed in connection with the fault already described. This breccia consists of fragments of white chert with some blende in a matrix of gray dolomite, black secondary chert, and a little calcite. The fragments of original chert are sharp angled and so thoroughly splintered that the breccia resembles closely a mass of tailings from one of the mills of the district cemented by matrix materials. Such thoroughly shattered material is not uncommon, and there is everywhere evidence that the chert and limestone have been squeezed and broken.

Brecciation and faulting are closely associated throughout the district. They occur together along zones of fracturing. The same stress has been relieved at one point by brecciation and at another by definite fracturing or faulting. Brecciation is far the more common, and this seems an expression of the general law that stresses are relieved more frequently by many small fractures than by a few large ones. The great zone of fracturing and brecciation followed by Center Creek, between Webb City and Cartersville, has already been described. The similar zone stretching from Cartersville to Prosperity has also been mentioned. Another important zone of fracturing and brecciation extends from the gas works at Joplin southeast to and across the Banker tract. It is followed part way by Joplin Creek and was the scene of some of the earliest mining in the district. It is at present marked by many important and rich mines. These zones of fracturing and brecciation are very important in their relations to the ore bodies and by their extent and general richness give promise of long-continued yield. They show conclusively that, measured by the total amount of energy expended, deformation in the Southwestern district has been very important.

FOLDING.

Broad, low folds are doubtless common in this region as elsewhere, and some evidence of their presence has been obtained in the course of the present work. It will require further detailed studies to locate and trace them and to determine their relations to and influence on the fracturing, brecciation, and distribution of ore bodies. Close folding seems to be extremely rare. In one of the American mines at Center Valley the best instance seen in the district was examined. The fold here has a breadth of approximately 300 feet and a known amplitude of 40 feet more or less. The course is roughly north-south and has been followed a few hundred feet. To the north the fold dies out, and on three sides accordingly the strata bend down. The dip is rather steep. The overlying material here is Coal Measures shale and the fold has produced in this material an elliptical dome-shaped structure. Under the shale the chert is thoroughly broken. This breccia was quite rich in ore. The shale being impervious has here prevented the escape of ascending ore-bearing solutions and the ore body has accordingly been formed under the shale arch or dome. The structure and conditions are essentially similar to those of the Bendigo gold district of Australia, as described by Rickard.[1] So far such conditions have been found to be extremely rare in this district.

RELATIONS OF ORE BODIES TO STRUCTURE.

In the Southwestern district the location of the different camps, and within the camps of the major runs, has been determined by the structure of the region. The waters of the Cambro-Silurian are under hydrostatic pressure throughout the district. The particular points at which they have come up and mingled with the waters in the Carboniferous limestone, and at which, as a result, the ores have been developed, have been determined by the presence of fractures deep enough to cut the Devono-Carboniferous shale. Individual ore bodies may or may not be developed near these fractures. Crushing and brecciation in the Carboniferous limestones is widespread, and solution has been active throughout the district. As a result ore-bearing solutions have wandered widely from the fractures along which they gained entrance. The location of the ore bodies proper was determined by conditions favorable to deposition, and these conditions were not always very closely related to the structure. Probably in most instances the ore bodies are closely related to zones of fracturing, but in certain cases deposition has occurred by metasomatic replacement or by the growth of crystals in soft shale in unfractured material. Fracturing, brecciation, and solution effects are, however, more widespread than are ore bodies. This is expressed by the miners' statement that in certain cases they have "good ore-bearing ground, but no ore." Ore bodies occur less commonly than ground, which, to all appearances, is favorably situated. The actual relations between the ores and the structural features of the region have been already pointed out in several instances. They can, perhaps, be made still clearer by additional illustrations.

Aurora camp.—The principal portion of the Aurora camp is represented in Pl. XVIII. Two of the faults have already been described. Others are represented on the map, and so far as possible the developed runs of ore are shown by the location of shafts and outlines of underground workings.

One of the best and most continuous runs of ore in the Aurora camp lies, approximately, 200 feet south of the fault described as running from the Myrtle J. to the Second National. This run will be spoken of here as the South run. It extends almost entirely across the Boston-Aurora tract and was worked in shafts 1 to 4 of that company. East of the No. 4 its continuation has not been found, though some ore is present as far east as the Sand Ridge fault, already described, and probably the territory is merely lean rather than barren. To the southwest the underground workings of the Boston-Aurora connect with the Jumbo. The general course of the run beyond the Jumbo is marked by the Bonanza, Nickel Plate, Betsy, the Louisa-World-Herald group, and so to the Coleman properties. This run is not a simple continuous body of ore, though it proved to be so from the Jumbo to the Boston-Aurora No. 4, in which portion of its course it was an irregular body of ore-bearing breccia from 40 to 150 feet wide and from 20 to 60 feet high. To the west the run bends a little to the south and, so far as present prospecting has developed it, the ore bodies there are not so closely connected. In general the run represents an irregular zone of fracturing and brecciation. Surface galena and calamine were found along portions of its course, in particular on the Brinkerhoff land. To the west there is a hard cap of little disturbed rock over the main ore body. In the Louisa-World-Herald-Ozark group of mines the general section is as below:

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[1] Trans. Am. Inst. Min. Eng., Vol. XX, pp. 463-545.

Section in Louisa-World-Herald-Ozark mines.

	Thickness.	Depth.
	Feet.	*Feet.*
3. Loose surface material—broken rock in red clay	50	30
2. Limestone and chert, horizontally banded and firm	35	65
1. Breccia with ore	30	95

The ore here seems to represent the first concentration, very little modified. It is in a well-cemented breccia of white chert, with a dark calcareous matrix. Here, as in other mines along the run, both calcite and dolomite are developed, and small water pockets or channels occur. The ore is principally blende, but includes a subordinate amount of galena and perhaps 1 per cent of iron pyrites. The ore "makes" against the cap, which indicates the action of ascending waters. The amount of mine water pumped bears no relation to rainfall. There is a surface run of silicate ore, but this seems to be cut off from the ore bodies below and is probably an instance of alteration of the surface run unaccompanied by enrichment of the lower bodies.

On the Brinkerhoff land the run was marked by very rich surface ores with enrichment below. A considerable amount of ores running 15 to 30 per cent in blende have been found on this land, and the deep drill hole at the Nickel Plate mine shows that brecciation and ore occur at intervals down to a depth of 500 feet. This depth of brecciation may be exceptional, since the Nickel Plate is only a short distance west of an important cross fracture running to the southeast and marked by the ore bodies of the Cleveland-Aurora and St. Louis-Aurora mines.

It will be noted that the South run has a generally direct and fairly persistent course parallel to the fault already noted as running from the Myrtle J. southwest; that it is marked by brecciation which is unequally developed at different horizons and distances along its course; that it shows in the better-protected portions features indicative of concentration by ascending waters and in other portions the secondary effects of superficial alteration and secondary enrichment. It is also to be borne in mind that in this case a drill hole proves that the brecciation extends down through the Devono-Carboniferous shale and into the magnesian limestones of the Cambro-Silurian.

The second important run in the Aurora camp may be called the Shale run. It is developed along the fault block which runs from the Myrtle J. to the Second National. In the Myrtle J., Boston-Aurora Nos. 5 and 7, the Bryan, and the Black Crook mines the ore is developed along the south side of the shale block. In the Boston-Aurora No. 5 it extends under the shale, and in their new No. 6 ore is found, as already described, along the north contact of the shale and limestone. The Big Sixteen shafts were located one on either side of the fault block. Farther to the southwest the Madison ore lies to the north, but probably within the influence of the faulting. The Dewey and Buckeye ore bodies are also to the north. In these mines no shale is seen, though certain now abandoned shafts to the south of their workings show its presence. The Second National is still working in the soft red ground of the upper levels, so that no certain structure can be made out. It is, however, in a general line with the other mines mentioned.

The Shale run shows an actual vertical displacement of more than 70 feet. The total thickness of the Boone formation here is 350 feet. In view of its brittle character and the known length of the fault, something more than 6,000 feet, it seems not unwarranted to assume here that the fracturing extends down to and through the Devono-Carboniferous shale, and that thus a way was opened for the upflow of the deeper waters. As usual the faulting was accompanied by widespread brecciation and in this belt of breccia the ores and associated minerals are irregularly developed. In most of the mines superficial alteration and the process of secondary enrichment have been very active. Original concentration against the shale bar and the bounding walls of the breccia has also been quite important. Where cross fractures come in, the workable zone swings out to meet them, as in the group of mines including the Johnny Bull, the Jack Rabbit, and the Madison. At other points the country rock is hard and unbroken. This is shown in a prospect drift driven north 190 feet from the Betsy into the territory between the Shale run and the South run.

The North Aurora run was first figured by Winslow.[1] It extends from the Blackland tract northeast, approximately parallel to the Shale and South runs, to the Sand Ridge fault. Its course, with recent connections between the various mines, is shown on the general map. This run has as yet been worked mainly at the upper levels, 60 to 90 feet, and the output has been principally galena and silicate. The run is along a zone of brecciation rather than sharp faulting, and in the ground now open the red clays show that oxidation has penetrated to some depth. The deeper and richer bodies of blende which may reasonably be expected to be found along it have not as yet been opened extensively. In the Baldwin mine, which is situated at the intersection of this run with an important system of cross fracturing, large and rich bodies of blende, with some galena, are being worked from drifts at a general depth of 140 to 150 feet.

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[1] Missouri Geol. Survey, Vol. VII, 1894, p. 614.

North of the run just described large amounts of excellent silicate ore are obtained from a nearly east-west run extending from the Flying Dutchman through the Christian, the First and Second Methodist, the Baptist, and so to the Congregationalist mine. Beyond the latter the run has not been located, though it has been prospected for. From the Christian there is a north-south run of ore through the Dog and Pup mines toward the Baldwin. The group of mines of which the Christian is the best known are taking silicate ore from shallow breccias having a red clay matrix. The sharp offset to the south, where the north-south intersects the east-west run, and the steep dips in the ore bodies are very suggestive of faulting, but in such disintegrated material it is not easy to be positive.

To the north, on the Seaman land, there are at least two faults of unknown extent, along which some ore has been found. To the south there is an important fault along which the Sycamore and Frounoy mines found ore. To the east is the Sand Ridge fault, already described. Along this fault important ore bodies are being developed by the Bowyer, Wheat, Rogers, and other mines. It affords a most promising belt for prospecting. The ores where found east of the fault line will be at more than the usual depth, since the overburden of Coal Measures must be penetrated before the main ore-bearing ground can be reached.

West of Aurora prospecting is now being carried on and there are numerous shallow pits from which galena was formerly taken. There is not enough ground open to afford much detailed evidence as to its structure, but the facts that are available indicate that here, as east of Aurora, the ore will be found mainly along certain definite belts or zones of fracturing.

In the Aurora camp there is not only good positive evidence of the general association of the ores with structural belts, but there is important negative evidence as well. If the map be examined it will be noted that the Royal, Queen, and De Long tracts show practically no mining, though they lie in the midst of the mining regions. In each case they seem not to be cut by any important zones of fracturing. The stresses in the rocks were apparently sufficiently relieved by the faults around them. The De Long tract has recently been prospected with exceptional care and thoroughness, and the drilling is reported to have shown no important ore bodies. In the Aurora camp, as throughout the district, minor amounts of lead and zinc are widely distributed, but the important and rich ore bodies occur along or near the main zones or belts of fracturing.

Continental tract.—The location of the main faults on the Continental tract is shown on Pl. XIX, and the faults themselves have been already described. The distribution of most of the ore bodies as developed by the underground workings is also shown on Pl. XIX. There is a close relation between the ore bodies of the Gobar, Mildred, B. & C., and Gilmore mines and the fault crossing the Boqua land. The Glendale, Clover Leaf, Foster, and Kohinoor ore bodies show an equally close relation to the fault crossing the northern portion of the Continental land proper. The Pearl and Tomahawk ore bodies are developed along the eastern edge of the main fault block, and the Manning, Live Mule, and Young mines stand in close relation to the western edge of the same fault block. The Trouble ore body is developed to the south and west of a minor but important fault, and many of the other mines show evidence of faulting.

The largest and most important ore bodies so far developed are found between the major faults rather than near them. There has been a great deal of superficial alteration and of secondary enrichment which tends to obscure original conditions. The ores are found in breccias and accordingly have extremely irregular outlines, a fact only imperfectly brought out by the small scale map here presented. It is difficult to make sure as to the presence or absence of any regular system of cross fractures in the ground between the faults, but the distribution of hard ground bars and soft ground and the plainly fractured condition of the rock indicate that the work of the waters in softening and dissolving the rock has taken place along certain zones determined probably by the course of minor fractures. The broad belt of ore bodies from the Glendale to the Manning seemingly indicates such a zone. The ore bodies in this zone are characteristically large, rich, and soft, and it is to be noted that in a general way this belt of soft and broken ground is indicated by the topography. The fault extending from the Gobar northwest also seemingly influences the topography. The Glendale fault, which is characterized by thorough cementation of the attendant breccia, has had no influence on the surface, and ore bodies along it may be expected to occur without relation to the surface relief.

Massasoit mines.—Many interesting features of the ore bodies and their relations to fracturing are illustrated in the Massasoit mines. The Massasoit land is located in the southeastern portion of Joplin, south and west of the Banker or Missouri Lead and Zinc Company's holdings in the NW. $\frac{1}{4}$ sec. 14, T. 27 N., R. 33 W. A small stream flows north through the land and into Joplin Creek. The mines are west of this stream and on the hill slope. Approximately along the course of this stream there is a fault of 100 feet with hard, horizontally bedded limestone to the east and soft Coal Measures shale to the west. A cross section of this fault is shown in fig. 31. The shales are found up the slope of the hill, but not on the divide to the west. Drill holes and shafts show that they increase in thickness to a maximum of 92 feet as they approach the fault. In a drift at the 110-foot level of the Massasoit No. 3 the hard limestone wall was cut 70 feet east of the shaft. At the contact there are large quantities of spar and dolomite, some of the gray dolomite being crumpled and broken. The shales and the limestones are also crushed, and bits of shale, coal, chert, limestone, and dolomite are found thoroughly mingled. In the Massasoit mines proper less ore is found in the spar ground along the fault than in the basal portion of the shale and along the contact of the shale and the underlying chert and limestone. The plane of contact is very irregular, as the main faulting was complicated by minor cross faulting, seen near the shaft to have a northwest course.

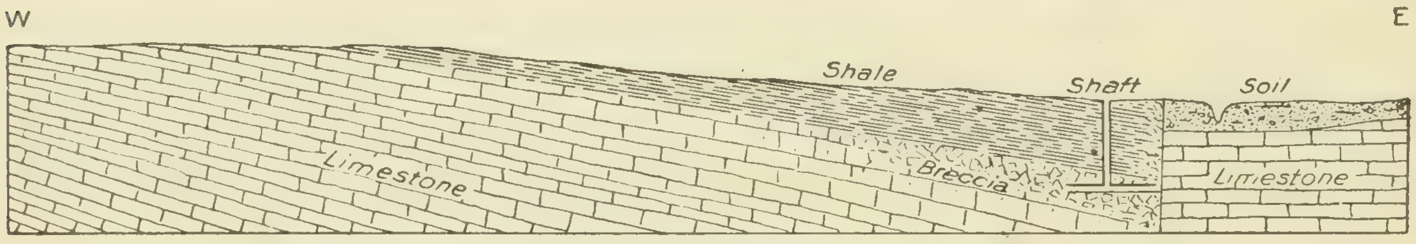


FIG. 31.—Cross section of fault at Massasoit mines, Joplin, Mo.

At the 70- and 95-foot levels considerable amounts of galena in pebble form were taken from the lower 10 to 12 feet of the shale. Below this is a variable amount of red ground, normally 10 to 12 feet in thickness, with galena in red clay at its base. Still lower is a loose mass of broken white chert, with some spar and a usual matrix of black selvage. This ground yields large amounts of blende. The black-selvage ground and the red-clay ground have a very irregular contact, and for some little thickness cut each other out quite irregularly.

The general conditions here indicate a fault by which a block of Coal Measures shale was tipped down into the limstone and chert. Mineralizing solutions ascending along the fault plane spread out along the base of the shale and produced dolomitization and original or first deposition of the ores in the shale and the underlying broken rock. Later oxidizing waters found their way from the ridge to the west down along the same plane, softened the ground, probably entrained more or less shale into the original breccia, oxidized the iron, thereby in part changing the black clay to red, carried the blende down to enrich the lower portion of the ore body, and even carried a portion of the galena down to the base of the belt of oxidation. The less altered ores may be seen in the spar ground, where the usual water channels lined with pink dolomite and set with crystals of chalcopyrite may be seen, and where calcite and bitumen are also more prominent.

The course of the main fault is a little west of south. It has been carefully traced for a distance of 800 feet and evidently extends much farther. To the south of the Massasoit it is marked by the Shamrock, Carthage, and Joplin, Four by Five, Brookfield, A No. 1, Essex, and Friday mines, and probably was influential in producing the ore bodies of the Star A. The ore is more abundant in the spar ground in the mines named than in the Massasoit. To the north the fault seems to run about to Gobar and Sixty shafts, near the intersection of the Kansas City, Pittsburg and Gulf and the Missouri Pacific railways. At this point it joins or crosses the main line of fracturing and faulting, which, with a general N. 20° to 25° W. course, runs through the Kirkbride and Banker lands and is followed in part by Joplin Creek. This latter run follows a rather broad zone of fracturing, faulting, and brecciation and is marked by a string of Coal Measures outliers, numerous mines, a frequent pronounced dip, and good ore bodies.

Duenweg mines.—The mines of the Boston-Duenweg Company illustrate the relations of sheet ground and breccias to horizontal and vertical faulting and the relations of the ore bodies to both. The shafts and underground workings on the tract are represented in fig. 32, redrawn from the company's map. The general section of the rocks is illustrated by a drill hole in lot No. 9 of the south 80 acres. It shows the usual interbanded limestone and chert to a depth of 128 feet. Below this is the heavy body of the chert, in this case 50 feet thick. Underneath the heavy chert is interbanded limestone and chert, penetrated to a depth of 12 feet. The rocks have been broken by two major belts or zones of fracturing and brecciation. These have a general north-south trend and are located one well to the eastern limits of the property and the other to the west. The first is marked by the Jack Pot–East End workings, and the second by the Newsboy-West End group. In the zones of broken rock are the rich bodies of ore-bearing breccia which made the property famous. They are developed in the upper chert and limestone and extend above the main chert body as much as 60 feet. There are also surface ore bodies along these zones and oxidation has extended downward in instances to a depth of 100 feet, though usually confined to the upper 50 feet. Between the two zones of fracturing there was a certain amount of horizontal accommodation by which the bedding planes of the chert were opened up. As a result ore has been deposited along these planes, producing normal sheet ground.

Deformation at Duenweg took the form mainly of brecciation rather than simple fracturing. There is, however, at least one clearly defined fault which is located on the map. Along this fault a bar or block of Coal Measures shales about 40 feet wide and approximately 500 feet long was dropped into the limestone to a depth of 100 feet. Mining was carried on along both sides of this bar, to the east in soft, open breccia, and to the west in hard sheet ground. The ore was found along the contact of the shale and the limestone, and in lot 30, at the southern end of the block, a very rich body of ore was found. The fracturing extends farther south than does the infaulted block, and was followed 70 to 80 feet in mining.

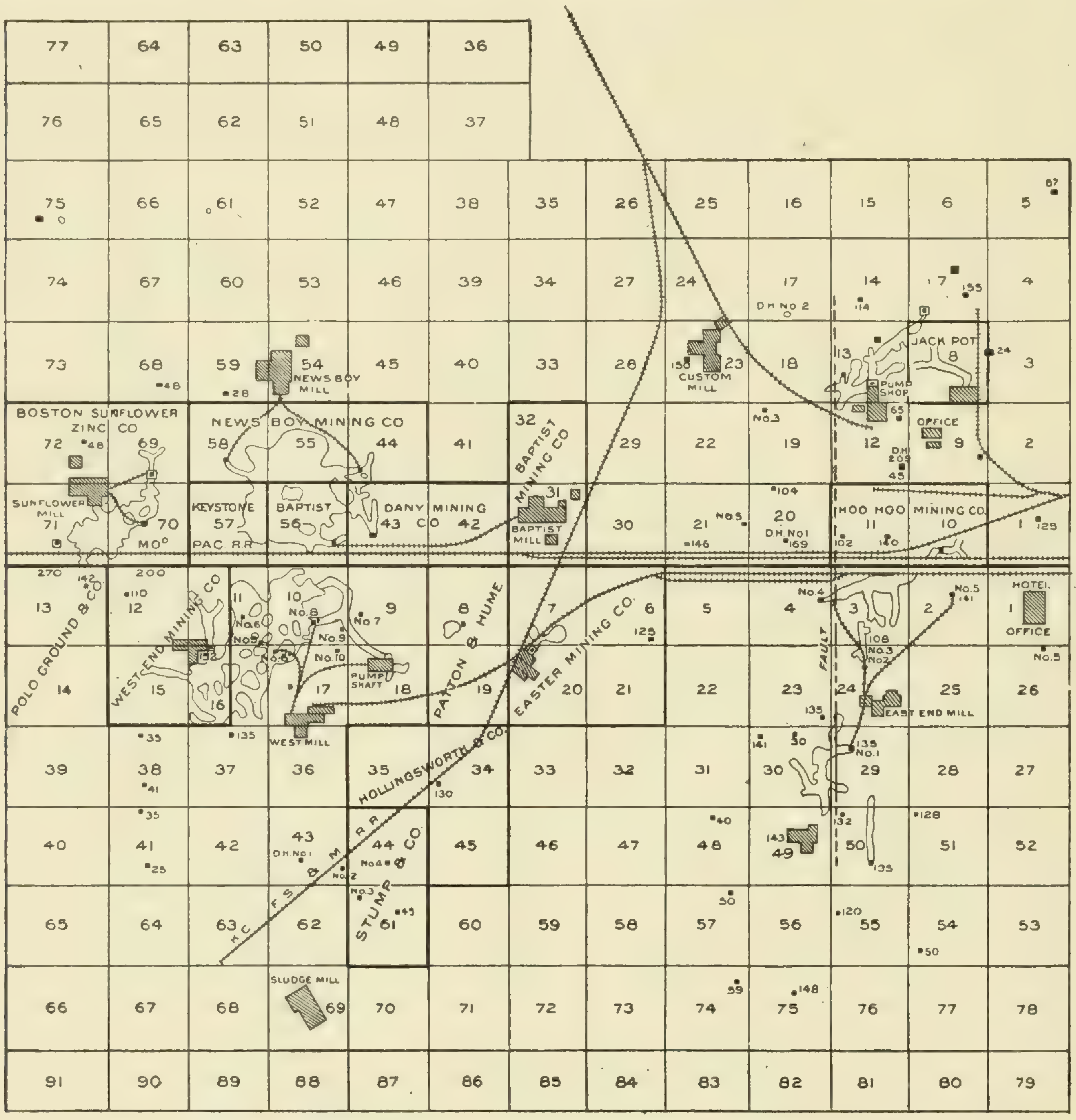


FIG. 32.—Map of underground workings at Duenweg, Mo.

In the main East End workings another shale bar is said to have been cut into at a depth of 120 feet southeast of the main ore body. The course and width of this bar are unknown. From the thorough brecciation of the chert, the occasional presence of pieces of coal, and the fact that much of the selvage material is evidently derived from disintegrated shale, it is inferred that numerous cross faults of considerable throw are present in the East End workings. The East End drifts are in soft ground, requiring close timbering, and have caved to the surface. They are known as hot mines, the heat probably being due mainly to the action of oxidizing surface waters on the sulphides present and subordinately to the heaving of the ground itself. The ore is essentially blende in a breccia consisting of white chert fragments and a black clay or selvage matrix.

The West End workings show the normal sheet ground with blende in a black chert matrix between horizontal, slightly brecciated layers of white chert. This sheet ground extends to the east and probably connects with that noted in lot 30; at least certain drill holes and the general nature of the deformation suggest this as probable. Above the sheet ground is a thick, irregular mass of breccia, in this case firmly cemented and not requiring timbering. It carries blende and galena with dolomite and shows the usual evidences of first concentration. A sump sunk to a depth of 30 feet below the floor of the sheet ground taps a strong flow of clear cold water charged with sulphates.

The Duenweg mines present a case of ascending waters producing dolomitization and a first ore deposition, principally along the main zones of fracture and subordinately in the horizontal chert along planes opened and slightly brecciated by horizontal movement. Along the eastern of these fracture zones descending waters later became important and produced a second concentration and rearrangement whereby the galena is now principally found in the shallow workings in oxidized material (Hardy shaft) and the blende in a lower, softened breccia. Here, in the presence of an excess of reducing material in the black selvage and shale, it was reprecipitated from the descending solutions. In part the concentration took place along definite contact planes and in part very irregularly through the breccia. Along the west zone of fracturing alteration and secondary enrichment have been very subordinate.

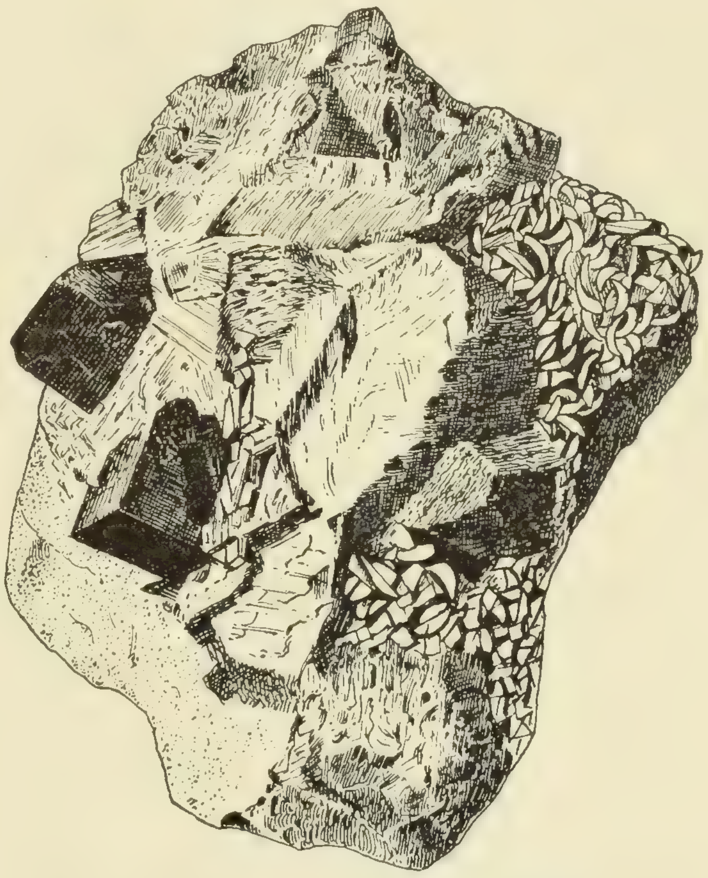


FIG. 33.—Ore breccia in limestone, Badger mine, Smithfield, Mo.

Galena camp.—In the vicinity of Galena, Kans., the limestone and chert of the upper interbedded portion of the section outcrops in the hills. The town and most of the mines are on relatively low ground. Hence, though Galena is not far from the edge of the overlying Coal Measures, the Galena ore bodies are characteristically cherty and the matrix is almost uniformly siliceous. This is due to two facts. In the first place, most of the mining is well down in the upper portion of the Boone formation. The limestones which are quarried near Carthage, and which are cut through in the mines on the higher ground west of Joplin, are found west of Galena and to the north, at the Badger and other mines in the vicinity of Smithfield (fig. 33). At Galena, however, they are largely eroded, though the Irene and Empire City mines go through them. The main mining is done below the horizon of the heavy limestone, and near, if not in, the heavy chert. In the second place, surface waters have acted to considerable depths in the vicinity of Galena, and such limestone as was originally present in the beds now making up the ore bodies has been largely carried off in solution. As a result of these two facts, the mines show the wide prevalence of breccias and shallow outlying basins of Coal Measures. Clean, sharp-cut faults do not seem to be especially prominent.

The general character of the mines around Galena is illustrated in a group or belt running out to the southwest from the town. These mines are located in a shallow, flat-bottomed valley, along which there are occasional pockets of Coal Measures shale reaching 20 to 30 feet in depth. In the low bounding hills interbedded limestone and chert occur. The ore is found mainly at depths of 65 to 100 feet in broken chert. A generalized cross section of the valley in the vicinity of the Mossback mine is shown in fig. 34.

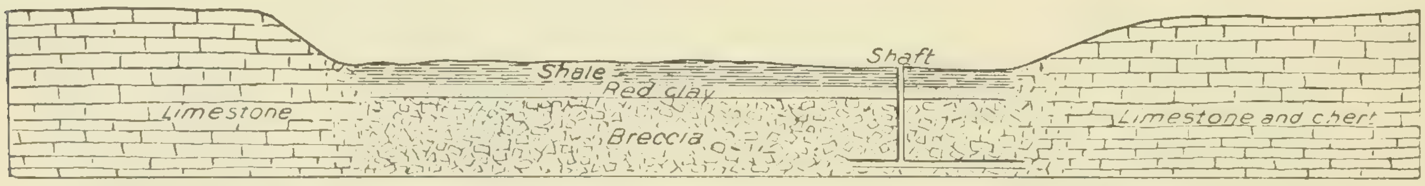


FIG. 34.—Generalized cross section at Mossback mine, Galena, Kans.

In the Mossback mine a certain amount of pebble ore, mainly galena, including a little blende, is found in the lower portion of the shale. More galena is found at the base of the irregular layer of red ground below the shale. Galena, blende, and minor amounts of pyrite occur in the broken chert and black selvage below the red ground. At the sides of the belt of broken ground is sheet ground showing galena and blende together in a black chert matrix, between the usual horizontal beds of white chert. At one point sheet ground is found below the main mass of broken chert. Here, as at Duenweg, Prosperity, and Center Valley, the main brecciated mass and heavy ores seem to occur just above the heavy bed of chert. The studies of the Galena area were not, however, exhaustive enough to make certain the continuity of the heavy chert here with that observed elsewhere, though the correlation is a very probable one.

The valley in which the Mossback mine is located seems either to follow a pre-Coal Measures depression or to have been developed along a belt of faulting sufficient to drop portions of the overlying shale below the plane of erosion. In either case it also has been the scene of brecciation. The ores were apparently first concentrated by ascending waters acting against the overlying impervious stratum. Later descending waters, finding a path along the plane between the shale and the brecciated chert, have, as usual, sorted the ores, carrying the blende below water level and even transporting much of the galena as far as the base of the belt of oxidation. Where by the abundance of organic material the ores were protected from oxidation the blende and galena are still found together, as in the base of the shale and in the black material of the breccia below water level. That transportation was effected mainly by oxidation to sulphates and precipitation as sulphides is indicated by the practical absence of carbonates and silicates.

The underground workings of many of the mines in this valley are connected and the ore occurs very irregularly throughout the valley. Whether the sheet ground extends far under the hills is not known, as the hill areas seem to have been very inadequately prospected. The Gold Bug, which is the deepest mine in the valley, has the usual ore body at a depth of about 100 feet. The shaft extends 48 feet below the ore and at that depth is in horizontally bedded, barren white chert. The flow of water is said to increase greatly with depth.

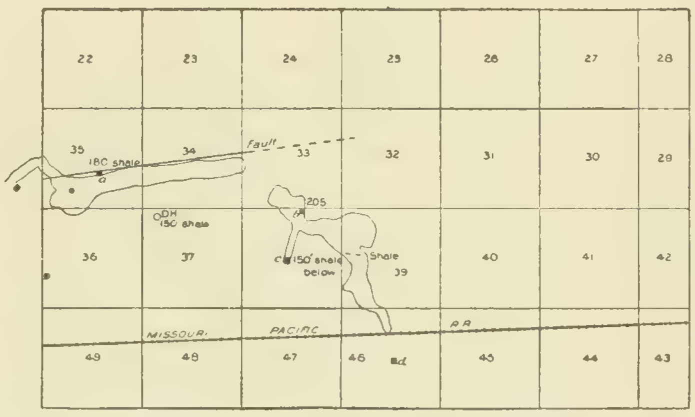


FIG. 35.—Map of Pleasant Valley mines, Carthage, Mo.

Pleasant Valley mines.—The Pleasant Valley mines are located about 3 miles southwest of Carthage (sec. 17, T. 28 N., R. 31 W.), on the Missouri Pacific Railway. The main underground workings are shown in fig. 35, from a map by Capt. C. B. Dahlgren. The ore body worked from shaft *a* is developed along a fault with a general course of E. 15° N. A cross section showing the relations of the fault and the ore body is shown in fig. 36. In sinking the shaft 60 feet of Coal Measures shale were penetrated. Below this was found a thin bed of loose brecciated ground carrying a shallow run of galena. Below this, brecciated but thoroughly cemented limestone and chert is present to a depth of 180 feet. At the latter level the mine is now being worked. The ore body is 20 to 40 feet wide and 20 to 35 feet high. The north wall is hard-bedded limestone and chert and is quite regular, following the fault line. The south wall is irregular and made up of breccia similar to that of the ore body, but barren. The ore body consists of a chert and limestone breccia, carrying blende and calcite but no galena. Dolomite is present, though rare. In lot 37 there is a drill hole showing the shale to be 150 feet thick, with limestone and chert below. In shaft *c* of lot 38 the same thickness was found. In a horizontal drift in lot 39 the shale caved in at about 180 feet below the surface, and it was there discovered that the drift had for some distance been driven about 10 feet below the shale.

The drifts running south from shaft *b*, which is 205 feet deep, show sheet ground. The blende occurs in thin sheets between beds of unbroken limestone and chert. At the base of the drift is a continuous sheet of very clean blende from a few inches to 2 feet thick. The ore is said to extend to the south limits of the ground, and a new shaft (*d*) is being sunk to cut this run. North of the shaft sheet ore is also seen. It is said that at the north end of the drift soft red bowlder ground was encountered. At this point the only important deposit of galena in the lower levels was found. Work is now being carried on in lot 33 to connect the two workings.

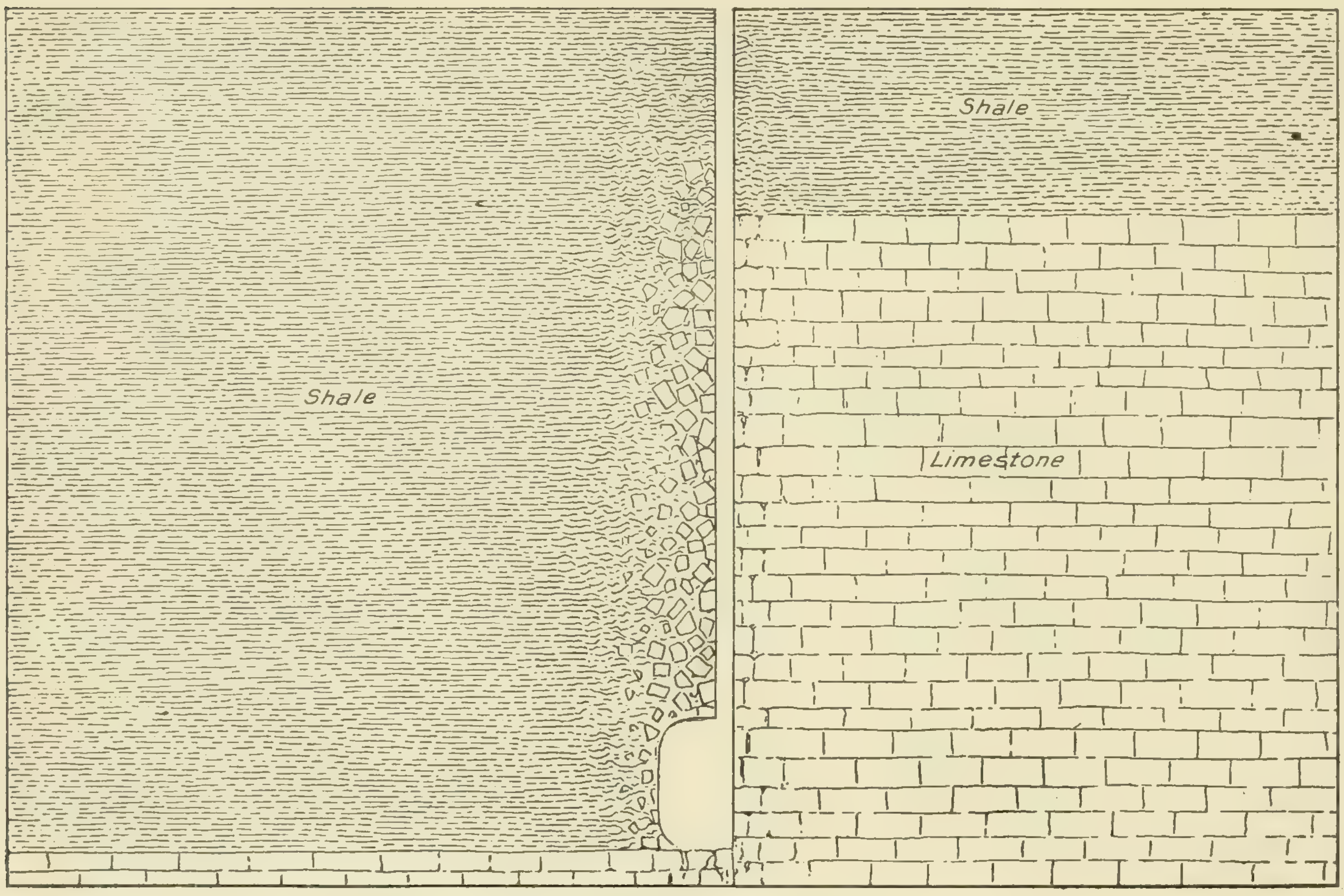
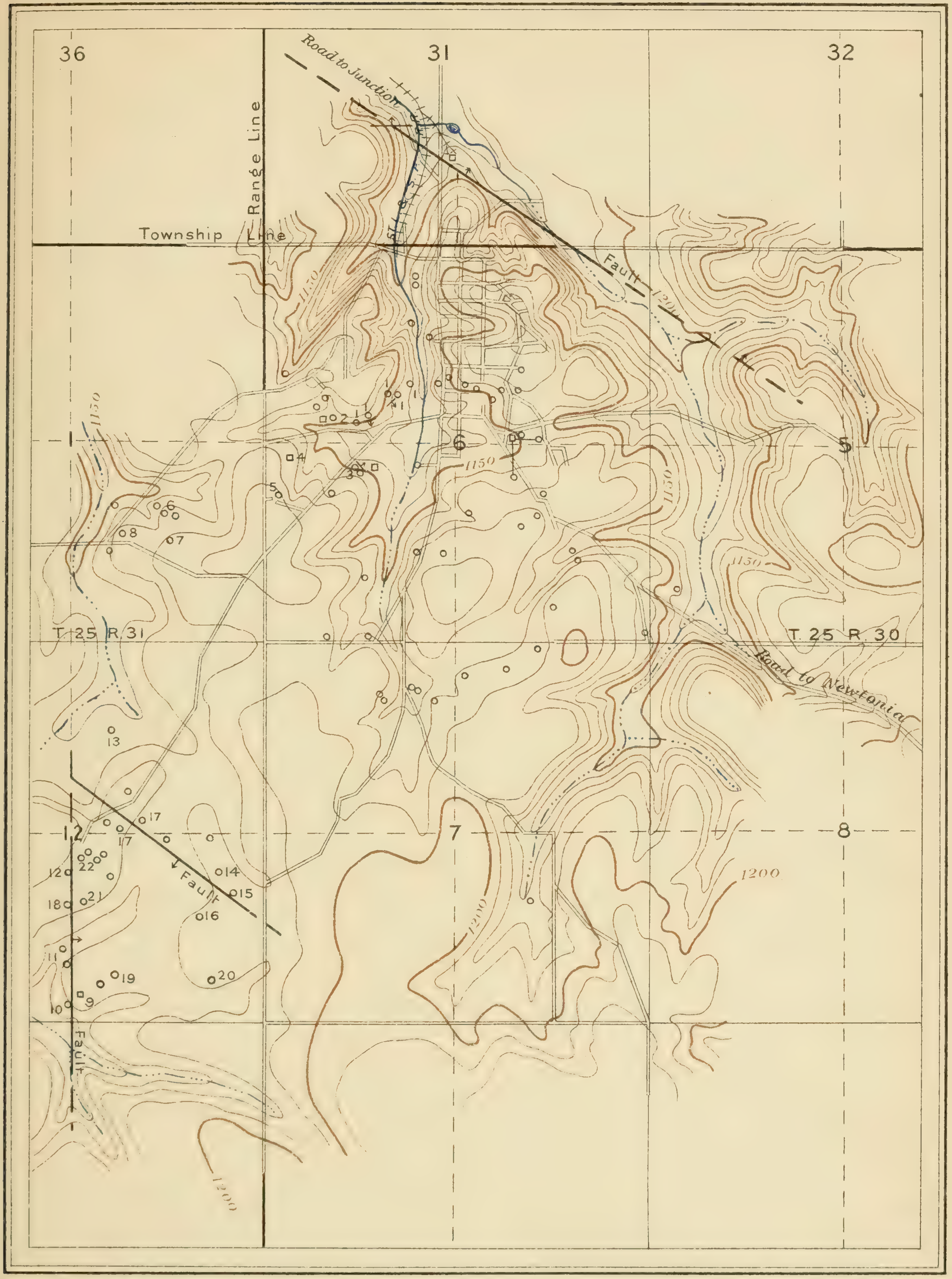


FIG. 36.—Cross section at Pleasant Valley mines.

The difference in the depth to which the Coal Measures extend gives evidence of a fault here with a throw of 90 feet. This fault has a course E. 15° N., and the ores were evidently introduced along it. They spread irregularly to the south in the fault breccia and in all directions as horizontal sheets at the base of the shale. The east workings indicate a probable minor cross fracture with northwest-southeast trend. The comparative scarcity of dolomite is notable, as is also the rather unusual freedom of the blende from admixture with galena. These things may indicate an absence of deeper waters, but it is by no means certain that the phenomena now open to observation are not deceptive in these particulars. The depth of the fault, the thorough brecciation, the complete cementation, the almost entire absence of oxidation, and presence of ore in the base of the overlying shale all agree



1 SUNSET GROUP
2 MORNING GLORY
3 WYOMING
4 PEACH TREE
5 CAMPBELL
6 GEE WHILIKENS
7 BEN HUR
8 MAY FLOWER GROUP
9 MASCOT
10 HOMESTAKE
11 LITTLE FOUR
12 HOMESTAKE 2
13 RAGGED THREE
14 CLARA BARTON
15 FUTURE
16 CRABAPPLE
17 JACK SPROUT
18 M & M
19 LADYSMITH
20 LUCKY TRUMP
21 HUNGRY JAY
22 TRILBY

○ MINE
□ MILL

TOPOGRAPHIC AND MINING MAP
OF THE
GRANBY (MISSOURI) CAMP

Scale
1 ½ 0 1 MILE

Contour interval 10 feet
TOPOGRAPHY BY W. H. GRIFFIN

JULIUS BIEN & CO. N.Y.

well with the hypothesis of a first concentration by ascending waters. The separation of the galena and blende and the superposition of the one on the other indicates the modifying action of descending waters.

Granby camp.—A complete survey of the Granby mines was not attempted, but a preliminary study brought out certain features which it seems worth while to present at this time. Granby is one of the oldest and best known mining camps of southwestern Missouri. It has yielded and still yields very large amounts of galena and silicate of zinc from shallow workings. The camp is everywhere known to mineralogists because of the number and variety of the carbonates, silicates, and other secondary minerals which are found there. The workings now extend to depths of 100 feet or more, and in recent years blende has formed the major output of the camp. The topography and distribution of the mines is shown on the accompanying map, Pl. XX.

The ores now worked occur mainly in breccias developed at the horizon of the upper interbanded chert and limestone. This upper member is shown by drill holes to have a thickness of 200 to 230 feet. The Devono-Carboniferous shale has been recognized in a number of drill holes in section 31, near the fault represented on the map. The shale occurs here very regularly at a depth of from 275 to 305 feet. Above it is a heavy dark-blue to black chert varying in thickness from 15 to 60 feet. In certain drill holes the lower portion of the black chert is replaced by interbanded chert and limestone, which reaches a maximum thickness of 20 feet. Above the black chert the beds are usually so broken and altered that identification of particular horizons is very difficult. In the Homestake mine, in section 12, the following section was found:

Section in Homestake mine.

	Thickness.	Depth.
	Feet.	*Feet.*
4. Surface clay and broken chert	20	20
3. Limestone and chert interbanded	135	155
2. Broken chert and dolomite	45	200
1. Chert, bearing ore	35	235

In a drill hole in the Mascot mine hard chert was found to extend in depth from 158 to 221 feet. At 191 to 201 some limestone appeared and excellent ore was found. From 221 to 400 feet there is no detailed record of the drilling, but limestone and chert were reported. The Devono-Carboniferous may have been cut without recognition in these, as in other drill holes in the camp. The Homestake mine and the Mascot drill hole records start from practically the same level, which is approximately 100 feet above that at which the drill holes in section 31 begin. If there were no faulting, the heavy chert body found at the Mascot and the Homestake between depths of 150 to 230 feet would be the probable equivalent of some of the brecciated beds in the upper portion of drill holes in section 31. There is, however, important faulting. The fault running along the north edge of the camp through sections 31, 6, and 5, traced by Mr. Willis, has a throw to the north of at least 80 feet. Other faults are known to occur, and it seems not improbable that the heavy chert of the Homestake-Mascot section is to be correlated with the bluish or black chert of the drill holes. In this event it seems probable that it represents the cherty beds commonly found in the upper portion of the lower member of the Boone formation. The general section of the rocks at Granby would on this basis be as given below.

General section at Granby, Mo.

	Thickness.
	Feet.
7. Surface clays and chert	0–20
6. Coal Measures shales and sandstones	0–80
5. Limestone and chert, interbanded and irregularly broken and brecciated	135–240
4. White, bluish to black chert	15–60
3. Limestone and chert interbanded	0–20
2. Shale and shaly clays	15–30
1. Magnesian limestone and chert.	

In this section the amount of surface clays is variable, since disintegration and superficial rearrangement extend to different depths in the various parts of the camp. The amount of Coal Measures material depends mainly on the extent and distribution of the faults. Over most of the camp Coal Measures are entirely absent. Material possibly belonging to Coal Measures is, however, reported at a depth of 120 feet in a drill hole near the center of section 12. The character of the upper limestone and chert is extremely variable, as is also the amount of brecciation and disintegration which it has suffered. Most of the ore worked is found in it. Numbers 3 and 4 of the section represent the lower portion of the Boone formation and have a usual total thickness of approximately 60 to 70 feet. The limestone of No. 3 merely replaces a portion of the chert. The two beds seemingly belong together. The black chert frequently carries an important ore body. The Devono-Carboniferous (No. 2) also carries ore, which has been already discussed. Below it are the magnesian limestones, cherts, and sandstones of the Cambro-Silurian, which have been penetrated to a depth of 840 feet. At the smelter there is a well drawing its supply from that depth. The water rises to within 40 feet of the surface and is a boiler water of excellent quality. The ordinary mine waters are different in character in that they are contaminated with sulphates.

In the Granby area there is evidence not only of brecciation, but of general deformation and faulting. Along the north fault, already referred to, there is a throw of more than 80 feet, as is shown by the presence of Coal Measures shales and sandstone to that depth in drill holes along it, with the underlying cherts and limestones rising in the hills to the south. The displacement of the Devono-Carboniferous and lower beds has already been mentioned. Near the fault line on the hill west of the Mount Pleasant mill, Coal Measures sandstones have a dip of 35° N. The strike here is N. 80° E., but the general course of the fault is shown by the contact of the shale and the chert to be approximately S. 70° E. To the southeast, in section 5, the displacement disappears and the fault is marked by brecciation of the chert and limestone and development of ore bodies.

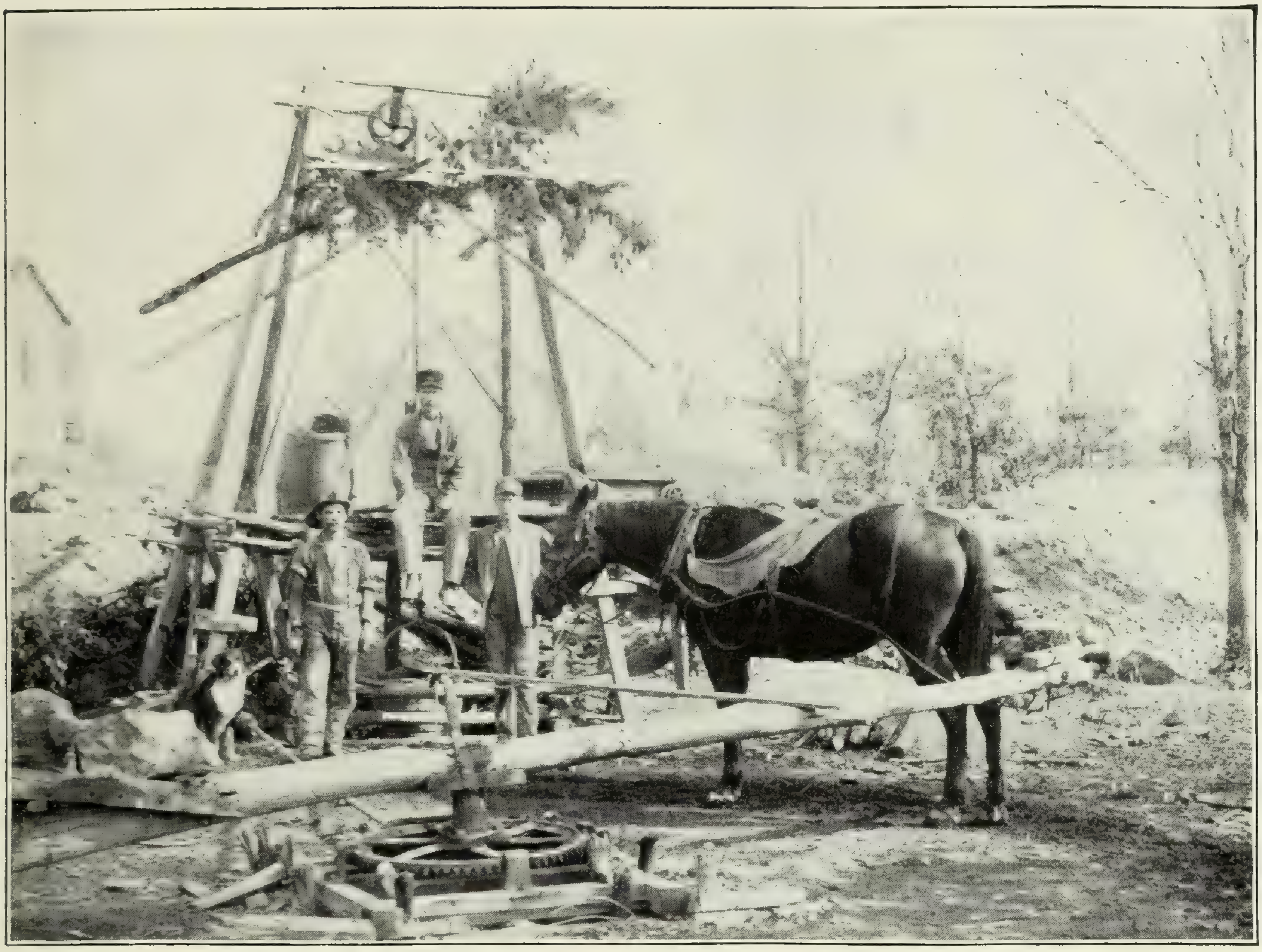
Southwest of Granby, in section 12, are the Mascot and other mines of the Prairie diggings or circle. In the Mascot mine, and again in the Little Four and the big open pit between, there are unmistakable evidences of faulting and brecciation along a course almost due north. The downthrow, which is to the east, does not seem to be important. A second fault runs northwest past the Future, Clara Barton, and Jack Sprout mines, intersecting the Mascot fault a little north of the center of section 12. This fault has a downthrow to the west, and the result is that a V-shaped block has been faulted down, with the maximum throw at the apex. Within the V shales, sandstone, and a hard quartzite, all of which belong to the Coal Measures, occur. The thickness of Coal Measures material decreases to the south. The ores of the "circle" are developed mainly along the two fault planes. The effort to close the circle and find ore across its southern side has been almost entirely unrewarded. To a certain extent ore has spread out laterally from the fault planes, and some ore may be found, as in the Ladysmith, away from the main bodies. Near the Lucky Trump good ore is reported to have occurred at a depth of 100 feet, and the size of the old dump indicates that mining was carried on here extensively. This may represent cross fracturing or an independent ore body; there being no opportunity to study the mine, it can not be stated which.

The well-recognized presence of bars of various sorts of material in other parts of the camp indicates that detailed studies will show numerous faults and zones of fracture. In part, deformation has bent the strata, and phenomena of this character are clearer here than in any of the mines elsewhere observed in the district. This bending of the strata and its relations to the ore bodies are particularly well exhibited in the mines of the Sunset group.

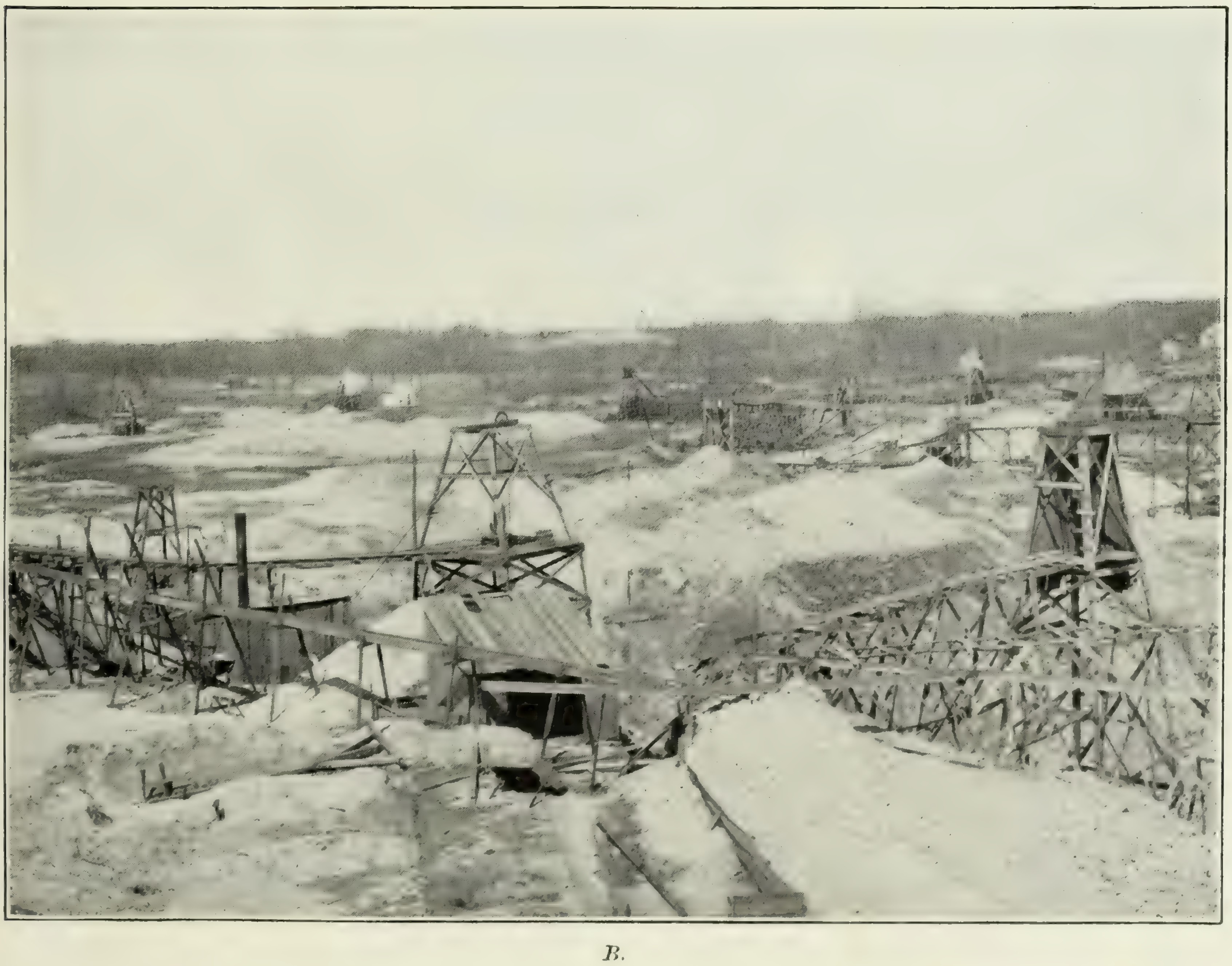
The Sunset mines are located along the hillside in the NW. ¼ of sec. 6. They form a curved line of shafts, following the contour of the hill, and the main workings are 75 to 100 feet below the surface. The ore occurs in a form of sheet ground, but the strata, instead of being horizontal, dip from 3° to 30° to the south and east, the dip increasing downward and the strike following the contour of the hill. The overlying beds are only moderately disturbed, except the uppermost 30 feet, which consist of residual clay and broken rock. The immediate cap in the mine workings is an arenaceous limestone, known to the miners as sandrock. It is found interbedded with the chert, where the latter is worked for ore, and has been involved in the brecciation which the chert has suffered. The main brecciation has occurred along the bedding planes as a result of the strata slipping over each other, but brecciation across the bedding also occurs. In the sheet ground the ore occurs between beds of white chert in a black earthy calcareous gangue and in red clay. The bulk of the ore body is the white to bluish chert. Dolomite and calcite are abundant, and small water channels lined with both, well crystallized, are frequent. Farther up the dip, and in ground above the present workings, galena was formerly found in quantity. Lower, but at the top of the ground now open, silicate of zinc is the main ore, with a subordinate amount of blende altering to silicate. Calcite, dolomite, and traces of copper carbonate occur at this horizon. Still lower down blende becomes more prominent and eventually dominant as the red clay disappears. The blende shows secondary enrichment, as is evidenced by small, clear crystals of brown blende set on the calcite, dolomite, and older blende linings of the water channels. Most of the workings now open are below the normal ground-water level.

Across the valley from the Sunset mines are those of the Wyoming group, in which the dip is also approximately toward the valley, and accordingly the reverse of that observed in the Sunset. This dip or pitch of the rocks with the surface and toward the valley is said to be a common phenomenon of the camp, and affords strong ground for believing that the streams in general are located over the main lines of disturbance in the underlying rock.

While the Granby rocks show exceptionally well the results of superficial alteration, and carbonates and silicates have always been abundantly produced, certain of the ores show also the features characteristic of original or first concentration. This is true in particular of the ores found in the black chert and the Devono-Carboniferous shale. At present these ores are known only in the Homestake mine and by drill samples. They show the common association with dolomite, the dominance of blende, and the constant association with the latter of subordinate amounts of galena and iron pyrites. Many of the drill holes in section 31 show a body of nearly clean iron pyrites



A.



B.

CHARACTERISTIC EQUIPMENT OF SMALL MINES IN SOUTHWESTERN DISTRICT.

A, Horse hoist, Klondike, Mo.; *B*, Small steam hoists, Lehigh (Mo.) mines.

at 253 to 257 feet in depth. This probably marks the lower limit of the second concentration and is interesting as showing that here, as in other regions, the final result of the second concentration is the segregation of the three sulphides, galena, blende, and pyrites, in bodies in which, with succeeding depths, each in turn is dominant.

SUMMARY OF SOUTHWESTERN DISTRICT.

The camps and mines described illustrate the general conditions and many of the peculiar details of the Southwestern district. They illustrate what are believed to be the characteristic phenomena of the district and point to the essential conditions which have determined the deposition of the ore and the nature and form of the ore bodies. They show the following general facts:

(1) The ore bodies of the district include three general classes: (*a*) Ores of first concentration; (*b*) ores resulting from oxide enrichment, due to superficial alteration; (*c*) ores enriched by secondary deposition of sulphides.

(2) The ore bodies in their broader aspects are related to certain structural features, among which the most important are the zones or belts of brecciation and faulting. These belts have directed the flow of the underground waters and have afforded the space for the deposition of ore.

(3) The ore bodies in their detailed features exhibit great irregularity, but usually show definite relations to certain broad and easily determined phenomena: (*a*) The ores of first concentration stand in close relation to the belts of fracture; (*b*) the ores of the belt of superficial alteration are mainly related to present topography; (*c*) the sulphide-enriched ore bodies are definitely related to the level of underground water.

CENTRAL DISTRICT.

The Central district was very little studied in the course of the present investigation. A few days were spent in it, and several properties were examined. From Winslow's description of the district[1] and other published sources it is believed that the properties seen were typical, and that the conclusions drawn will be found to have general application.

The country rock of the Central district consists of dolomitic and magnesian limestones, with which are interbanded certain coarse-grained sandstones. The limestones represent two types. The one is a massive to heavy bedded dolomitic rock, coarsely crystalline, and frequently of an open, porous texture. The other is the type known locally as "cotton rock," and is finer grained and usually shows thinner bedding. Along bedding planes in both types of rock there are earthy to shaly partings which may attain a thickness of several inches. These partings are, as compared with the dolomite, impervious. Along the northern and western edge of the district the limestones and sandstone of the Cambro-Silurian pass beneath the nonmagnesian limestones of the Carboniferous. Between the two a shale bed representing the Devono-Carboniferous may be seen in Benton, Morgan, Moniteau, and other counties. In the Central district the ores are found in rocks below this shale.

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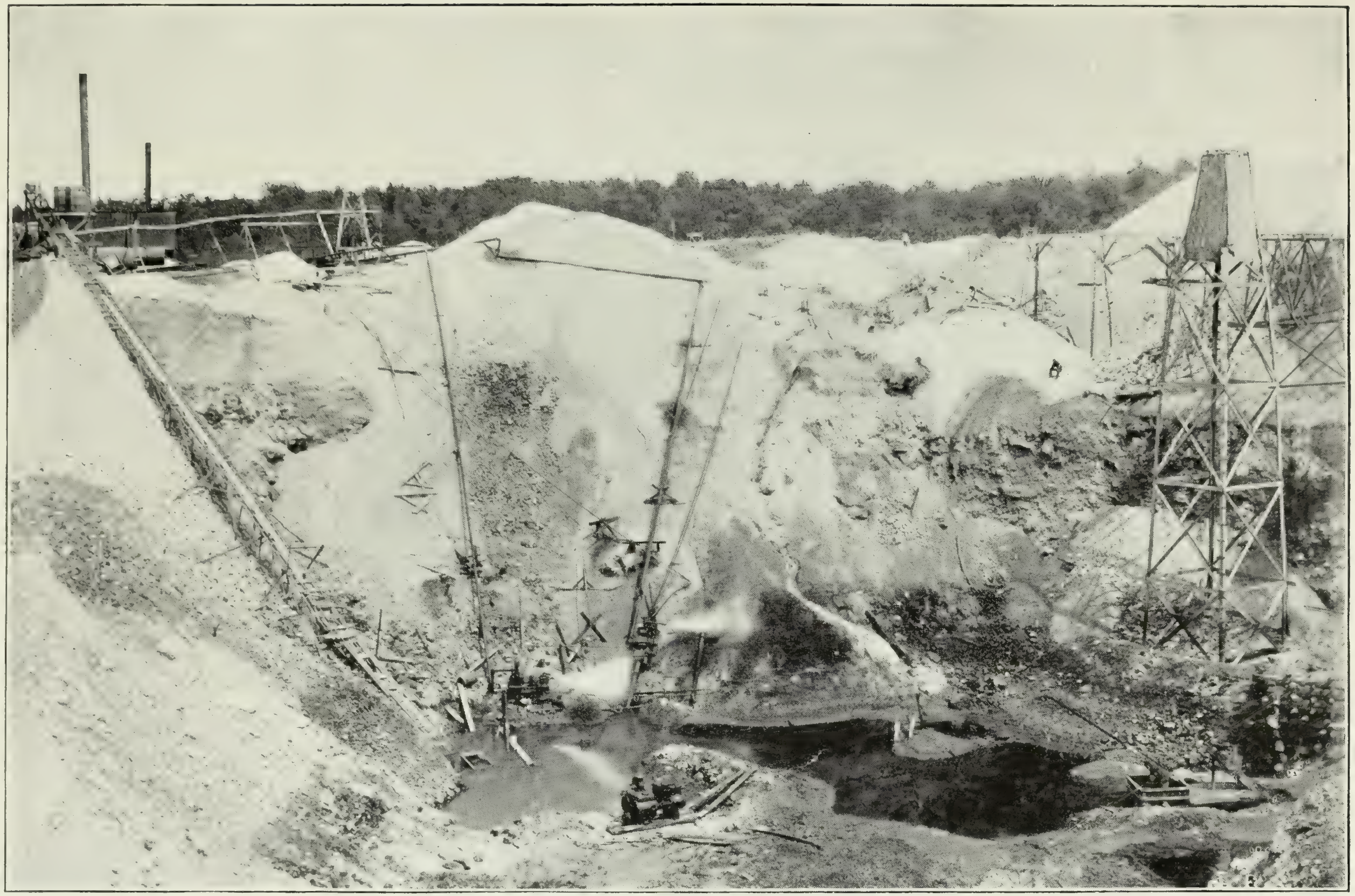
[1] Missouri Geol. Survey, Vol. VII, 1894, pp.702-724.

The ore bodies of the district are usually crevice and small circle deposits. As already indicated, the latter are probably in many cases sink holes in which the ores have accumulated mechanically and residually. It is not believed to be safe, however, to assume this origin for all of them. The ores so far marketed have consisted mainly of galena, which has been found most commonly in red clay associated with barite. Zinc carbonate is found, and a limited amount has been marketed. At the water level it occurs with some blende and barite, and below water level considerable bodies of blende are now being found.

The rocks have a gentle dip to the north and west, i. e., away from the dome of the Ozarks. Their edges are beveled by an erosion plane which has a slant in the same direction. At present the portion of the section which is being prospected is cut off from the central upland by the deep valley of the Osage. Accordingly there can now be no direct flow of water down the dip into these beds from the center of the Ozarks. There is every reason to believe that there was such a circulation before the valley was cut, and as the region was then largely covered by the shales of the Upper Carboniferous, and possibly by the Mississippian beds, many of the conditions favorable for the formation of ore deposits were doubtless present. Even now there are at least local instances of ascending water. In one of the Hoover shafts, near Hansbury, in Benton County, water under some pressure was found. The shaft was carried to a depth of 70 feet in the ordinary well-bedded magnesian limestone. At this depth 2 feet of thin, fine-grained, shaly limestone was cut, and below it a strong flow of water had just been struck at the time the mine was visited. Whether this is due to local causes or to deeper circulation passing under the Osage can not be stated.

Well-marked faults, with a throw of 90 feet, occur in the district. One of the best examples of faulting was also seen at the Hoover mines. At these mines the country rock is a fine-grained, sandy dolomite. A body of Coal Measures shale with a trend a little north of east is present, and extends to a depth of 96 feet in the dolomite. This shale block is about 75 feet across. Its length is not certainly known, though there is a local belief that the outcrop is roughly elliptical rather than linear. Ore is found along the edge of the shale. A



CHARACTERISTIC OPEN-PIT MINING, LEHIGH, MO.

shaft on the eastern edge was sunk 96 feet in shale. Galena occurred in it at a depth of 9 feet and continued from that to 35 feet, where blende appeared. The latter was rather rich for 14 feet in depth, and more or less blende and galena extended to the present bottom of the workings, with concentrations at the latter level and at 75 feet. When visited, the main opening was at the contact of a sandy-textured magnesian limestone and the shale. In the shale were angular blocks of limestone, of shale itself, and of the greenish shaly rock which forms partings in the limestone. The matrix was a soft, shaly material in which galena and blende occur in pebble form. The underside of a big tipped slab of the "cotton rock" was richly studded with blende crystals. The fault seems to be nearly vertical.

At the west edge of the shale block, and about 5 feet beyond the contact of the shale and limestone, is another shaft. At a depth of 60 feet this shows a very plain fault, with a throw of 4 feet and a hade toward the shale. Along the fault plane is a body of galena 8 inches wide, with a variable amount of barite. Whether the shale here be merely a block faulted in or an outlying remnant in an erosion basin in the limestone, there evidently has been faulting along the contact, followed by the introduction of solutions and the deposition of ore. The simplest hypothesis seems to be that of a block of Coal Measures shales faulted into the limestone with a first concentration of mixed sulphides by waters ascending along the fault planes and a later concentration and a partial separation of the ores by descending waters working along the same planes.

Brecciation occurs in the Central district, though it is not so important as in the Southwestern. At the Pitman mine, south of Versailles, in Morgan County, the horizontal beds of dolomite have been shattered and brecciated, and in the interstices and along the bedding planes galena, blende, and barite have been deposited. The major shattering has taken place in the cherty layers and in the sandy material which is found along the bedding planes. At the Flick and Reed and other mines the dump shows a well-developed breccia of good mill dirt grade.

SUMMARY OF CENTRAL DISTRICT.

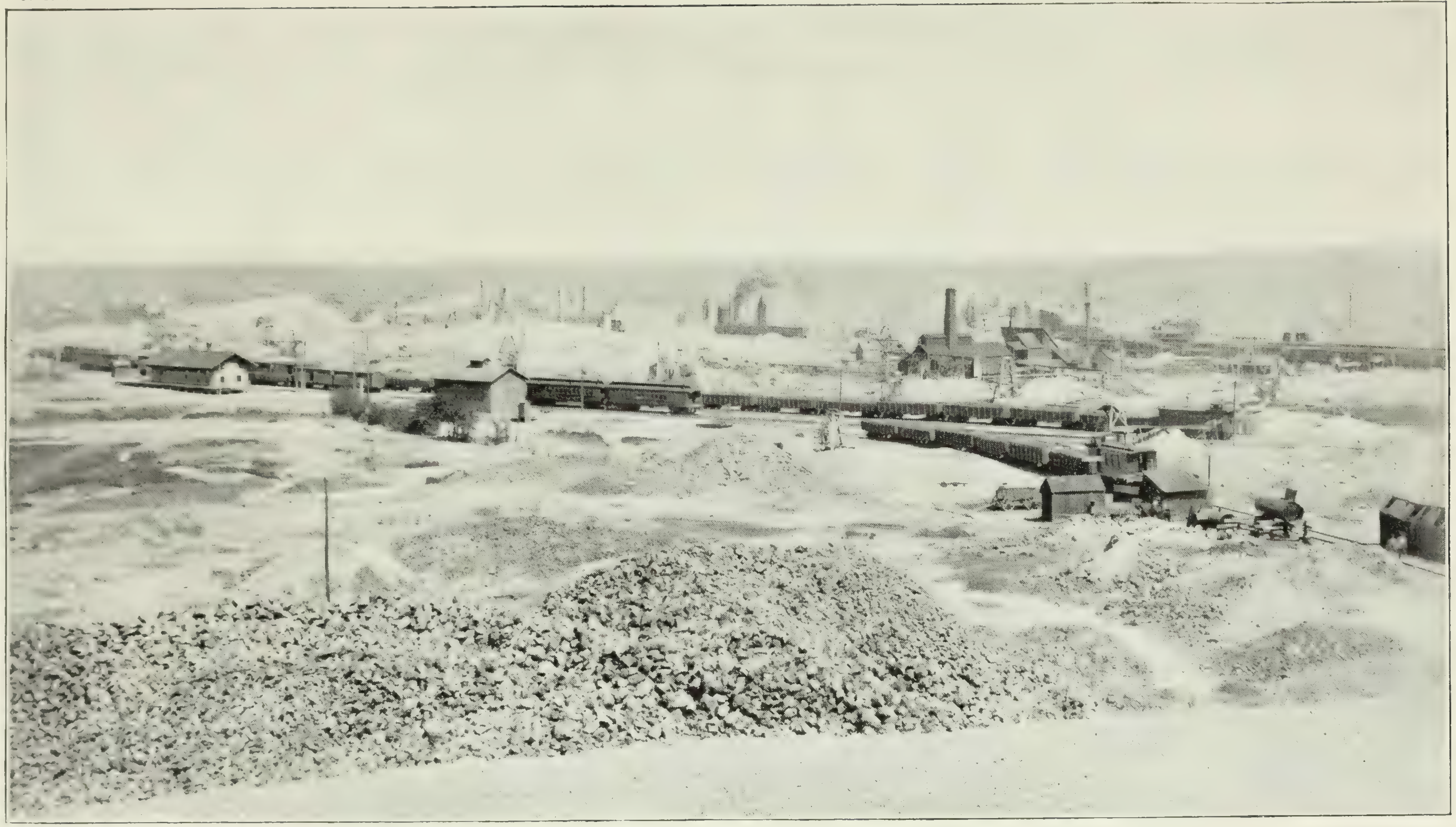
The Central district, so far as yet developed, is characterized by crevice and circle deposits with, in general, much smaller ore bodies than those of the Southwestern district. The association of the ores is also somewhat different. In the presence of faulting, brecciation, and evidences of the action of both ascending and descending waters the district resembles the Southwestern. The effects of descending waters are the more obvious and, as regards ore bodies now present, the more important. There is no single widespread body of rock which was permeated with reducing waters, and the original deposition of the ores probably was dependent on the mingling of solutions at the crossing of fractures and the local presence of organic matter in shale partings in the limestone. That underground circulation is now active throughout the region is indicated by the wide presence of springs, natural bridges, lost rivers, etc. The same facts may also be appealed to in order to show that in this case the movement is now essentially downward and toward the deeper valleys.

SOUTHEASTERN DISTRICT.

The Southeastern district is commercially second only to the Southwestern. Because of time limitations it was very little studied in the course of the present work, and accordingly no attempt will be made to discuss it. It is merely desired to state some of the features in which it resembles the Southwestern, and to give a general statement of the problems of the district as they appear in the light of results obtained elsewhere.

Aside from the large bodies of disseminated lead ore worked in St. Francois and Madison counties, the ore bodies of the Southeastern closely resemble those of the Central district. The Merrimac mine in Franklin and the deposits near Potosi, in Washington County, have been described already.

The disseminated ores of St. Francois and Madison counties were not studied in detail, though some mines have been visited. It is believed that the same general principles which controlled the deposition of the ores in other districts have operated here. The pre-Cambrian crystallines which form the base upon which the Cambro-Silurian dolomites and sandstones rest are much nearer the surface than in the other districts. In fact, they protrude through the sedimentary beds, and are exposed in the peaks of the St. Francis Mountains. Around the edges of the latter, and extending under the dolomites and dolomitic limestones which make up most of the Cambrian section, are certain basal beds, occasionally conglomeratic but usually arenaceous. These are believed to form the main underground channels of circulation by which waters falling on the slopes of the mountains are carried downward under the limestones of the valley. In the latter situation hydrostatic pressure would force them upward into the limestone along any available fractures, or, in the absence of the latter, through the porous dolomite itself. This flow would be checked and controlled by an impervious bed, and, particularly if the bed chanced to carry an excess of organic matter, deposition of any sulphides present would be likely to occur. These conditions are fulfilled at Mine La Motte by the superposition of the La Motte sandstone, the "white rock," and the "black rock." The two last-named beds are divisions of the Fredericktown dolomite. The black rock is a dark-colored, shaly limestone, including many thin bands of slate.



MINES IN CENTER CREEK VALLEY, WEBB CITY, MO.

It represents the Lingula shales of the region, and its lower portion is a most reliable ore horizon. At Doe Run the shales were again commonly present, and in the Bonne Terre–Flat River region they are frequently exposed. It is probable that careful study will show that they have a very definite relation to the ore bodies.

There is important faulting in the Southeastern district, but brecciation is so rare as to be practically absent. The ores do not seem to be closely related to the disturbances in the rocks, though doubtless fracturing, in so far as it has affected underground circulation, has been influential in the production of the ore bodies. In general, however, the solutions seem to have traveled through the rock itself, and the deposition has been by metasomatic replacement. The influence of the direct mingling of solutions from different sources was not as important as elsewhere.

The mines present a special case coming under the general class of concentrations by deeper water. In this case there is no reason for believing that the upward component of the journey was important. The waters may have penetrated to some depth in the crystallines, but of this there is no direct evidence, and the major circulation was in all probability along the path already indicated. The practical absence of blende is probably a matter of considerable significance, but its explanation may well wait upon fuller knowledge of facts.

NORTH ARKANSAS DISTRICT.

INTRODUCTION.

Reconnaissance work only was carried on within the North Arkansas district. During this time about thirty mines and prospects in Lawrence, Sharp, Baxter, and Marion counties were examined. The region is one which requires a more detailed and prolonged study than the author has been able to make before any general conclusions regarding it are warranted. It is proposed here merely to describe certain features which seem to link it with the other districts, and which indicate that many at least of the processes important in the latter have also been operative in northern Arkansas. For detailed descriptions of the individual properties the reader is referred to the excellent report recently issued by Professor Branner.[1] In this report and in others issued by the Arkansas survey[2] the general geology of the region is discussed. The detailed stratigraphy of the Ordovician, which is the local representative of the Cambro-Silurian, is yet to be worked out. Because of the fact that many of the ore bodies form blanket veins, this stratigraphy is of exceptional importance.

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[1] Zinc and lead region of North Arkansas, by John C. Branner: Rept. Arkansas Geol. Survey for 1892, Vol. V, 1900.

[2] See, in particular, Manganese, by R. A. F. Penrose, jr.: Rept. Arkansas Geol. Survey for 1890, Vol. I, 1891; Marbles, by T. C. Hopkins: Rept. Arkansas Geol. Survey for 1890, Vol. IV, 1893.

GENERAL GEOLOGY.

In an earlier section of this paper Mr. Adams has given the general geological section for this district. The mining is practically confined to the Ordovician, and is most active near the north front of the Boston Mountains, where the upper portion of the assemblage of beds composing those mountains is exposed. Throughout the mining regions of Boone, Marion, Newton, Searcy, and Baxter counties the Boone chert is found commonly on the ridges, while the valleys have cut down into the Cambro-Silurian magnesian and dolomitic limestones. The Devono-Carboniferous shale is not an important member of the series in this district. To the northeast, in Lawrence and Sharp counties, the Carboniferous rocks have been removed and the country rock seems to be entirely Ordovician. Along Rush Creek and Buffalo and White rivers there is an important sandstone, usually 20 to 30 feet thick, occurring not far below the base of the Boone chert. If this be considered to be the Saccharoidal or "First" sandstone of the older Missouri classification, a probably correct correlation, the bulk of the ores are found in beds equivalent to the "Second Magnesian." In Lawrence County a sandstone, presumably the "Second," is found with magnesian limestones above and below. This would put the ores of that area, including certain counties in southeastern Missouri, in the "Second" and "Third" limestones. These correlations are suggested only, though believed to be probable.

COUNTRY ROCK.

Lithologically the Cambro-Silurian of the district is largely made up of three kinds of rock: (*a*) Sandstone, which does not serve as country rock to the ore bodies, but bids fair to be of considerable service in working out the detailed stratigraphy; (*b*) fine-grained, dove-colored siliceous limestone, occasionally very thinly bedded, always "plucky," and breaking with a clean conchoidal fracture; (*c*) a coarse, granular, blue to buff dolomitic limestone. Both sorts of limestone occur in connection with the ores and are found in the breccias. Near the mouth of Buffalo Creek the fine-grained rock is dominant through a thickness of about 500 feet below the "sand ledge" or Saccharoidal sandstone, which here, as throughout the district, is the best datum plane. The second kind of rock is by far the most common in the district as a whole.

ORES.

The district as a whole is marked by an unusual predominance of zinc minerals. Indeed, in the Rush Creek mines of Marion County and throughout Lawrence and Sharp counties the absence of lead ores is quite as striking as is the absence of zinc ores in the lead mines of Madison and St. Francois counties in southeastern Missouri. In northern Marion County, in the vicinity of Lead Hill, and in the adjacent counties of Missouri lead ores are mined, and within the area where zinc mining is active some lead is found. In Lawrence County the Gibson mine (SE. ¼ sec. 10, T. 17 N., R. 2 W.) is said to have been worked intermittently for seventy years for lead, and the dump shows galena, not associated with other minerals, in a breccia of dolomitic rock. At Roe's mine (NE. ¼ sec. 31, T. 16 N., R. 4 W.) galena and blende occur in interlocking crystals. The zinc ores of the district in general are, however, exceptionally free from lead.

The zinc occurs in the form of blende and in various forms of the carbonates. The blende is black to rosin in color and is of good grade as regards iron and is of exceptional purity. Very little iron sulphide occurs with it though both pyrite and marcasite are occasionally present. The blende has altered to carbonates very extensively. In many of the surface pits which are found throughout the district the carbonate alone occurs. In others the blende altering to the carbonate is found. This process has probably taken place through the alteration of the sulphide to the sulphate under the influence of surface waters. The sulphate at once reacts in the presence of the magnesium and calcium carbonates of the country rock, and is deposited as the carbonate of zinc, while the magnesium and calcium sulphates are largely carried off in solution. Occasionally, as at the Rock Springs mine in Sharp County (sec. 25 or 36, T. 17 N., R. 4 W.), a portion of the calcium sulphate remains in the form of little crystals of selenite, thus indicating the process of change. The carbonate of zinc is deposited from the waters as stalactitic growths and incrustations over the blende and rock indiscriminately. The incrustations of clean carbonate over fresh and apparently unaltered blende may be seen especially well at the Casper mine (NE. ¼ sec. 18, T. 16 N., R. 2 W.), in Lawrence County, and the Morning Star, on Rush Creek, in Marion County. The mixed blende and carbonate ores sell at reduced price, and the difficulty in disposing of them at a profit is one of the present hindrances to the development of the district.

In the shallow surface pits the most common gangue is red residual clay and the coarse dolomitic sand which results from the breaking down of the country rock. In the hard rock mines pink dolomite is the most common gangue material. Calcite occurs in subordinate amounts at the Morning Star mine, and quartz occurs at the Black Rock mine, on the Coke land (sec. 32, T. 17 N., R. 3 W.). It is here in the form of small but quite perfect doubly terminated crystals, in the red clays.

ORE BODIES.

Much of the ore so far marketed from North Arkansas has been taken from shallow surface pits. This represents both float material mechanically gathered together by erosion processes and residual material derived from decay along the outcrop of any form of ore body. In the former case there is no incentive toward deeper prospecting at that particular point. In the latter the ore may be expected to continue in depth to limits determined by the structure of the area and the genesis of the particular ore body. The true condition can be determined only when the workings have extended to or into the rock. In the unweathered rock the ore of the district occurs (*a*) as crevice deposits, (*b*) as runs and blanket veins in breccias, and (*c*) as disseminated ores.

Crevice deposits.—Fracturing and faulting are widespread and important throughout the district. Many of the more important faults are represented on the maps of the Arkansas survey.[1] In most instances observed the deformation has been accompanied by shattering along zones rather than by clean-cut fracturing along single planes. In the Sunflower mine, near Smithville (sec. 27, T. 17 N., R. 3 W.), a definite crevice 6 to 18 inches wide is filled with red clay and carbonate of zinc, with some blende. The crevice extends to a depth of 40 feet. Below that there are fine seams through the rock, but not a well-defined crevice. At Roe's mine, near Calamine, in Sharp County, there is a well-defined nearly east-west crevice which has been explored to a depth of 30 feet. The wall rocks are of the usual magnesian limestone, and there is no conclusive evidence of faulting. Breccia is developed along the crevice. In one shaft the crevice was seen to have been enlarged by the action of atmospheric waters till an opening having a cross section of 3 to 4 feet had been developed. This opening was followed some 20 feet in mining, and was found full of red sandy clay, tumbled blocks of rock, and some galena. At the same mine, where the vein matter is unaltered, the galena and blende occur together, with angular fragments of blue dolomitic limestone and a matrix of pink crystalline dolomite. A parallel crevice some 200 yards north is said to have been traced for a distance of a quarter of a mile.

Breccias.—The bulk of the ore occurs in somewhat irregular breccias. The breccias are of two sorts, which differ considerably in appearance and very materially in origin. The general character of one sort is illustrated in Pl. XIII, *C*, which represents a specimen from the Michigan mine in Baxter County. This breccia is made up of sharp-angled fragments of the country rock cemented by a matrix of pink crystalline dolomite and brown blende. Such a breccia shows that the rocks have been crushed and broken with a splintery fracture. Clean crystallized calcite occasionally occurs as a matrix, but portions of the limestone, recrystallized, may serve the same purpose. Breccias of this kind are the result of the crushing of the country rock,

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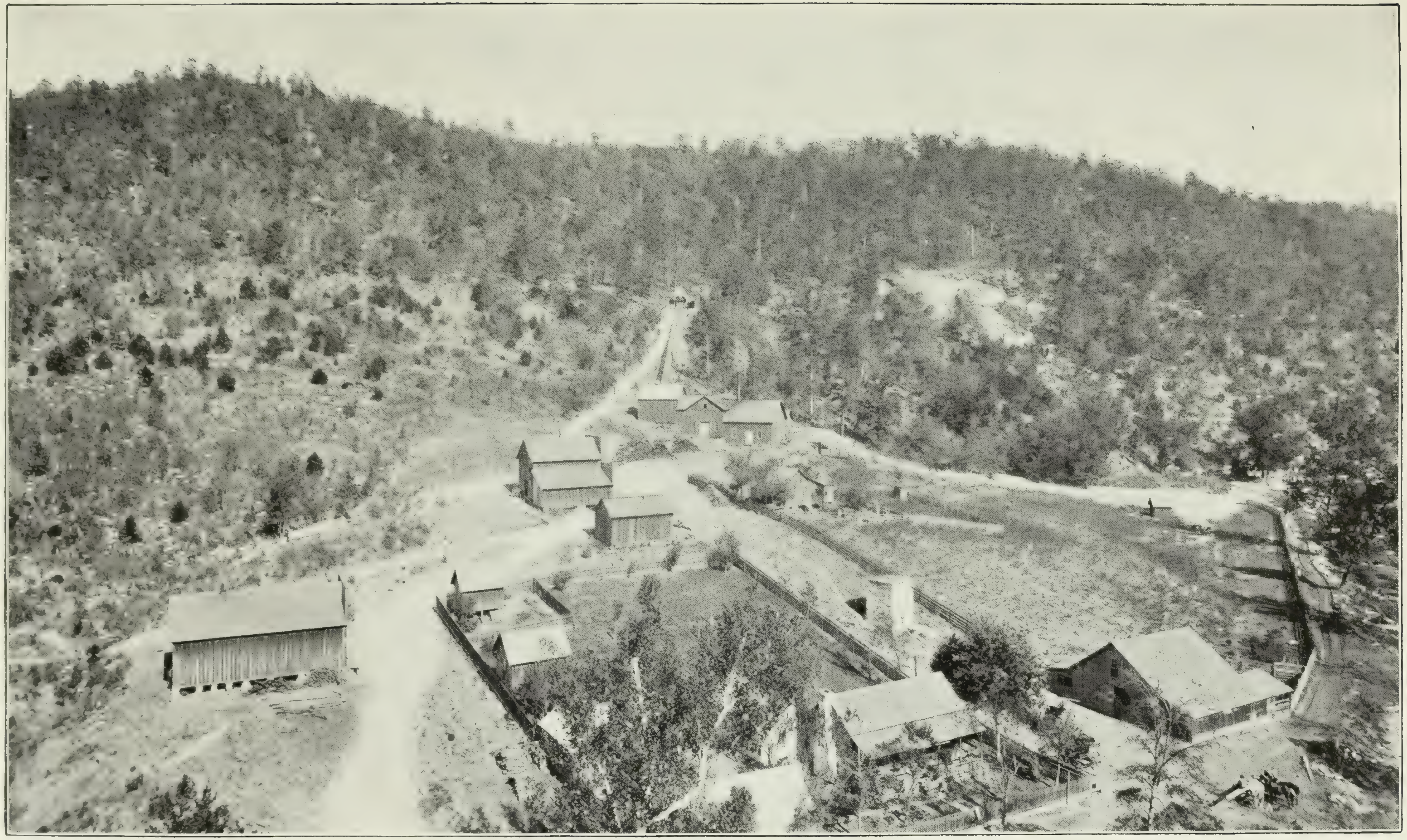
[1] See, in particular, Zinc and lead region of North Arkansas, by John C. Branner: Rept. Arkansas Geol. Survey for 1892, Vol. V, 1900, pp. 36–62; also T. C. Hopkins: loc. cit., atlas.



MORNING STAR MINE, RUSH, ARK.

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and may be expected to be developed in belts or runs having a linear distribution and a more extended vertical than transverse development. The ore at the Bonanza mine on Cow Creek (center sec. 10, T. 17 N., R. 14 W.) is developed in such a breccia, the general course of the belt being N. 75° E. The brecciation is in the fine-grained limestone already described. This rock, because of its greater brittleness, is more easily and extensively brecciated than is the common limestone of the district. The matrix at the Bonanza is mainly pink crystalline dolomite and brown blende. There are water channels through the breccia lined by crystalline dolomite. A tunnel carried a few feet in at one end of the cut shows a hard, horizontally bedded limestone at the side of the run. A shaft in the bottom of the cut shows breccia to a depth of 20 feet, making a vertical face of about 35 feet. It is said that the breccia extends 40 feet deeper, but this is now below water. About 1,000 feet away, along the strike of the belt of brecciation, a second pit about 40 feet above the level of the main opening shows a similar breccia. It is characteristic of this mine that the ore occurs entirely in the matrix of the breccia. There has been no replacement of the country rock, such as produced the disseminated ores elsewhere seen.

The Hoppe mine in Lawrence County (sec. 19, T. 16 N., R. 2 W.) shows clearly-defined brecciation along the course of a sharp monoclinal fold which changes at the surface to a fault. Considerable quantities of ore are said to have been taken from this mine by the old American Zinc Company in 1872, when they were smelting at Calamine. Brecciation is seen in many North Arkansas mines, where development is not sufficiently advanced to give any clue to the nature of the stress producing the brecciation or the direction from which the force came. The common conditions are seen in some of the mines of the Black Rock Mining Company in Lawrence County.

The second kind of breccia is a conglomerate. It is made up of pieces of country rock, broken probably by wave action when the rocks were young and cemented by a matrix of material similar in general composition to the material of the fragments. Such a breccia is developed parallel to the bedding and often occurs between unbroken horizontally bedded rocks. When such a breccia becomes impregnated with ore a blanket deposit is the result.

Such a conglomerate is seen at the Morning Star and neighboring mines on Rush Creek (Pls. XXIV and XXV), where it is associated with mud cracks (fig. 37) and other evidences of shallow-water deposition. The conglomerate itself shows pieces of limestone of at least four sorts in a calcareous matrix. The matrix carries a considerable amount of sand in well-rounded grains of sizes which differ from place to place, as if the sand had been sorted by water. It also includes soft greenish clay material in films and patches. The surfaces of these films show adherent sand grains. The Rush Creek conglomerate is about 250 feet below the "sand ledge." Along this horizon the limestone elsewhere shows fine laminations and thin beds so disposed as to be very suggestive, at least, of cross bedding, which confirms the idea that the conglomerate itself is due to shallow-water agencies. A similar conglomerate was seen at several points in the vicinity, but there was no opportunity to determine its relations.

Any stress operating on the conglomerates tends to crush them, because of their heterogeneous nature. Where conglomerates are crossed by a vertical belt of crushing, an ore body is likely to develop. The heterogeneous nature of the conglomerate not only makes it weak and easily broken when subjected to stresses, but renders it subject to ready disintegration through solution. Waters crossing it in any channel have a better opportunity to spread along it than is afforded by the harder limestones above and below. Ore crystallizes out in any cavities which result, metasomatic reactions take place between the ore-bearing solutions and the matrix, or even the pebbles, and a blanket deposit is formed.

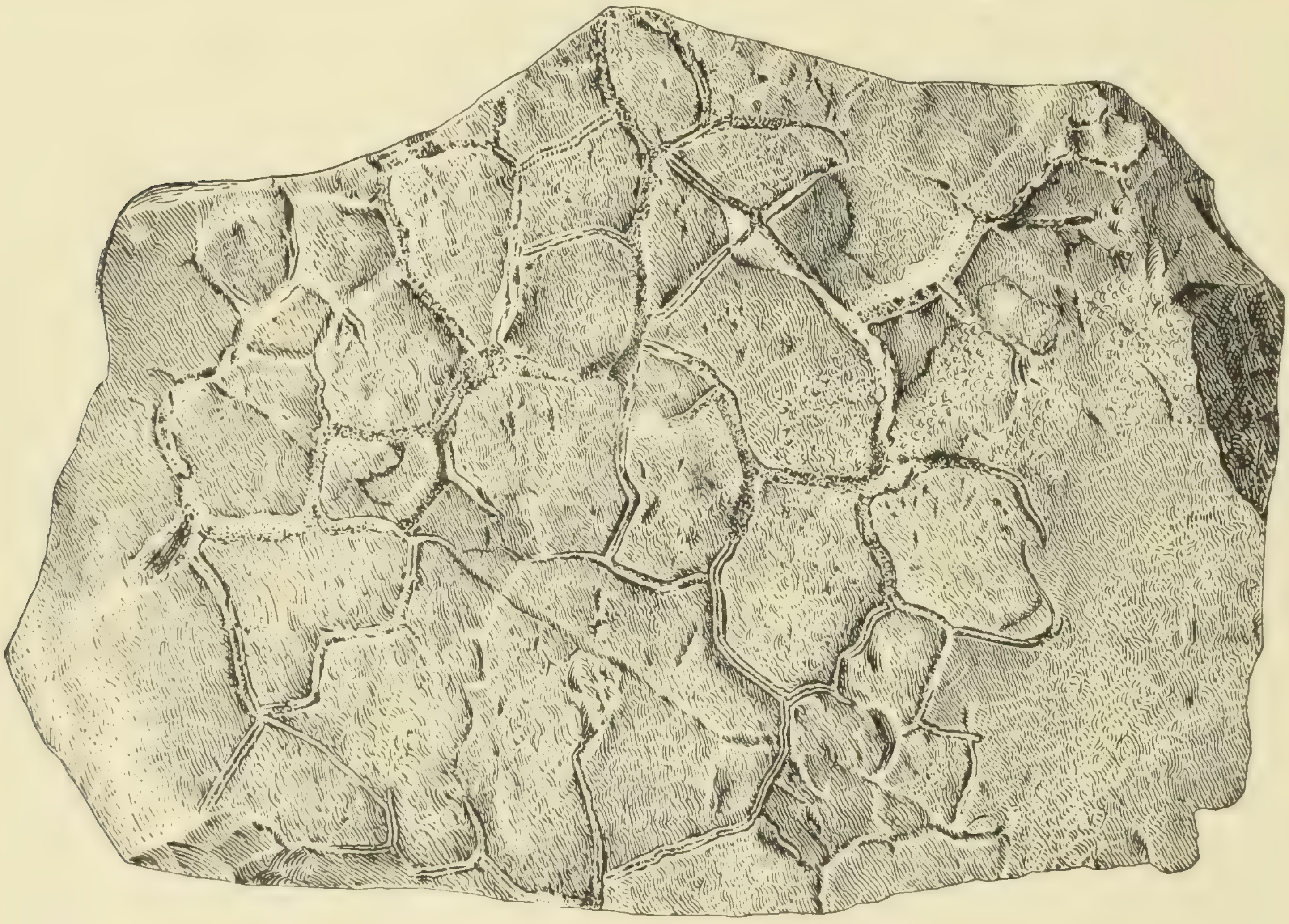
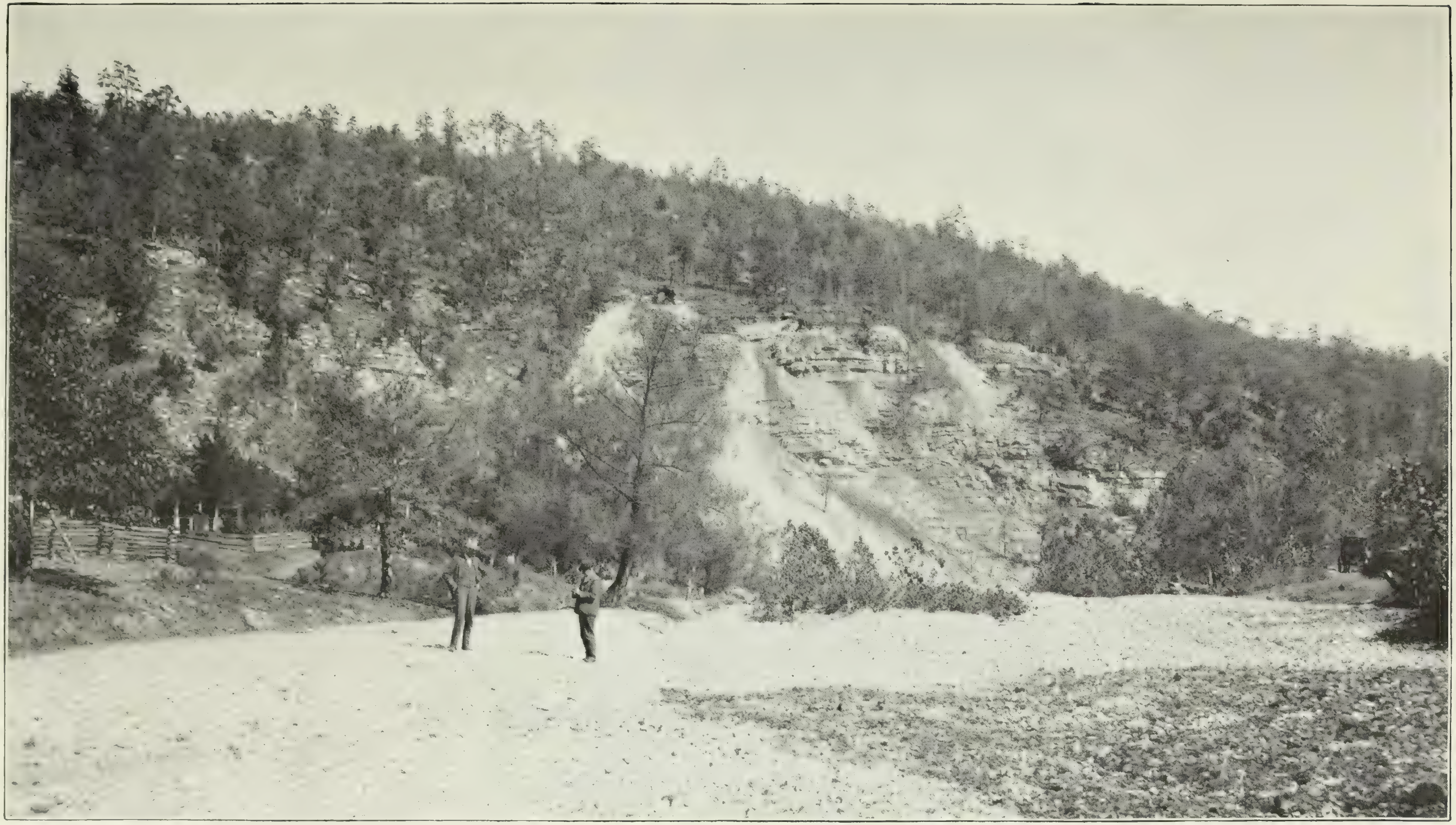


FIG. 37.—Mud cracks in limestone, Rush, Ark.

A typical example of such a deposit is seen at the Morning Star, White Eagle, Red Cloud, and Mackintosh mines on Rush Creek, in Marion County (see Pl. XXV). These mines are located along a belt of fracturing and folding. The main ore bodies are where this disturbance crosses a conglomerate interbedded with limestone. At the



MACKINTOSH MINE, RUSH, ARK., ILLUSTRATING A HILLSIDE EXPOSURE OF A BLANKET VEIN.

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Morning Star there is particularly clear evidence of faulting and disturbance in the rocks. At the east end of the main cut there is a fault by which the normal ore-bearing breccia is brought into juxtaposition with the thin bedded siliceous-looking limestone. Along the contact the beds of limestone show drag phenomena. Sandy material has been introduced along the fault plane and cemented by calcareous material. Carbonate of zinc and pink dolomite also occur along the fault plane and throughout the breccia. Branner has described in some detail the faulting in this mine.[1]

Disseminated ores.—Throughout the district there is a notable tendency toward metasomatic replacement of the country rock by blende. This produces an ore consisting of a limestone or dolomite not apparently fractured or broken and yet showing in cross section numerous small particles with partial crystal outlines of brown blende. At places the amount of blende is sufficient to produce a workable ore. The disseminated ore is more frequently found in connection with the conglomerates, though it at times occurs in unbrecciated and undisturbed rocks. The conglomerates and the disseminated ores both usually form blanket deposits, and their frequency is at once an argument for the essentially original nature of the metallic sulphides as regards the rocks of the district and an excellent augury for the life of the mining district, since bedded deposits are easily located and usually extensively mineralized.

SUMMARY OF NORTH ARKANSAS DISTRICT.

The ore deposits of northern Arkansas show many points of resemblance to those of the other districts discussed and some points of dissimilarity. In the character of the country rock and the common presence of carbonates the district resembles the Central and Southeastern districts. In the frequent tendency toward disseminated ores resulting from metasomatic processes the relations are especially close with the Southeastern district. In the considerable size of the ore bodies and their intimate connection with brecciation, as well as in the general dominance of blende and practical absence of barite, the district is most closely related to the Southwestern. In the frequent presence and considerable importance of conglomerate it differs from all the others. The evidence of a primary circulation by deeper seated waters is suggestive rather than conclusive. The association of the ores at the Roe mine is such as might be expected to result from such a process. In this district, as in the Central district, the larger ore bodies are developed in rocks now cut off by a deep river valley from the central upland of the Ozarks. It is accordingly difficult to conceive a general circulation downward from the central upland, southward, and upward in the mining area analogous to the underground circulation on the west flank of the Ozarks. If, on the other hand, waters having their source in the Boston Mountains be supposed to be instrumental in ore deposition, they must have traveled across the bedding rather than mainly down the dip, which seems improbable unless very frequent deep-seated fractures be present. The whole problem of the course of the underground waters in the district is yet to be studied, though there is widespread evidence of their activity. It is possible that secondary enrichment has not played so important a rôle here as elsewhere. If the close juxtaposition of clean carbonate and unaltered blende and the general freshness of the ores above water level be taken into account, it seems probable that the district is one in which the water level has recently been depressed. This suggests that the White River Valley is recent in origin, a hypothesis which would need careful investigation from several points of view. The main source of the ores for the district in general is believed to be the magnesian and dolomitic limestones of the Cambro-Silurian.

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[1] Loc. cit., pp. 190-199.

SOUTHWESTERN ARKANSAS DISTRICT.

Southwestern Arkansas is outside of the Ozark region, and was visited only incidentally. The Bellah mine, already described, is typical. The country rock consists of a series of folded and faulted shales and sandstones. The veins are fissure veins and the association of the ores is very different from that in the Ozark region. The deposits show interesting evidences of secondary enrichment and many phenomena similar to those relating to the ores of the other districts. Their general character is, however, very different and they form a wholly separate class of deposits, which will not be here discussed.

CHAPTER VIII.

By H. F. Bain.

SUMMARY STATEMENT OF THE GENESIS OF THE ORES.

The facts relating to the structure of the region and the occurrence of the ores have already been stated. The partial interpretation of these facts has been suggested. It remains to give a connected account of the hypothesis which it is believed best explains the origin of the ores and ore bodies. Different portions of this hypothesis are unequally sustained by the facts so far observed and the evidence for certain steps in the general process is much stronger in other fields than in the Ozark region. For convenience in writing, the whole is given in a connected and positive form. This is not with the intention of suggesting that fuller studies may not necessitate considerable modifications and additions, but to emphasize the belief that in the main the hypothesis here outlined is essentially correct and applicable. Its application to the ore bodies of the Southwestern district is especially close, and what follows refers particularly to the ores of that district. It is believed, none the less, that to a certain extent the ore bodies of the other districts were formed by the same process, and certainly the same general principles have controlled throughout the region.

CLASSES OF ORE DEPOSITS REPRESENTED.

Van Hise has discriminated three general classes among ore deposits resulting from the action of underground waters: (*a*) Ores which at the point of precipitation are deposited by ascending waters alone; (*b*) ores which at the point of precipitation are deposited by descending waters alone; (*c*) ores which receive first concentration by ascending waters and second concentration by descending waters.[1] Representatives of all three classes are found in the Ozark region.

It is needful to note that the terms ascending and descending, as used in this report, do not have the exact significance which has been given to them by usage in general discussions of ore deposits. The term ascending water has commonly been used in such a sense as to imply ascension from an indefinite and presumably considerable depth. Frequently it has also implied the presence of high temperatures and conditions unusual in the upper portions of the earth's crust. As used here the term is applied to the portion of the normal ground water which in its circulation has for that portion of the journey during which deposition of ore occurs a predominant or major upward, as contrasted with downward, movement. Descending water, as used here, includes that portion of the ground water which in its general circulation has a major downward movement during the time within which the ores were deposited. Locally the movement may be upward or lateral, but the effects are those of waters which on the average flow downward. The term descending water usually has been restricted to surface water penetrating downward to a limited depth. Occasionally the action of such water in producing surface residual accumulations of ore has been emphasized to such an extent as to distract attention from its very important transporting power and its action, through solution, on the ores themselves. The term is here applied to the downward-moving waters which have recently left the surface, in contrast with the upward-moving waters which have made a longer journey. Certain phases of the idea are expressed better by the terms older and younger, or waters of long passage as contrasted with waters of short passage. Ascending and descending are slightly misleading terms, because of the meanings which have in the past been read into them. For the underground waters of both classes, in this region at least, the real, dominant motion is probably lateral. While the terms ascending and descending are here used, it must be kept in mind that the emphasis is on the fact that the former represents the waters of the deeper and wide-reaching circulation, while the latter represents the waters of the shallower and essentially local circulation.

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[1] Some principles, etc.: Trans. Am. Inst. Min. Eng., Vol. XXX, p. 172.

It is not normally the direction of motion which is most important; it is the chemical constitution of the water. This is, however, so closely dependent in any given region upon the course that the waters have taken and the length of their journey that the character of the water can in most instances be easiest defined in terms of direction of flow. The sharp distinction between the two classes of waters and their influence in the deposition of ores has not always been well kept in mind, though Le Conte[1] and Chamberlin[2] discriminated them some years ago and emphasized the importance of the meeting of the two. The discrimination is one of very considerable importance.

RELATIONS OF THE ORES TO THE UNDERGROUND CIRCULATION OF THE REGION.

Probably few regions show better than this one the close association of ores with the general circulation of underground waters. This association has been emphasized in the descriptions preceding. Throughout the region the ores show marked increase in quantity with proximity to trunk channels of circulation. The ores are everywhere associated with faults and zones of brecciation, and the essential explanation of this fact is that circulation is easier and consequently the quantity of water moving is greater along such planes and zones. The largest and richest ore bodies are found either in open ground, where the circulation is now free, or in recemented ground, where breccias and other phenomena show clearly that circulation at one time has been free. Even within a breccia, whether firmly cemented or not, it is a common experience to find the best ore around the openings which formed the trunk channels of circulation. Hard bar ground, except where it represents formerly brecciated ground recemented, is not usually productive. Where ores are found in it the amount per cubic yard of material is small. In the language of the district, bar ground is "thin" ground and usually shows "shines" only.

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[1] Am. Jour. Sci., 3d ser., Vol. XXVI, p. 9.

[2] Geology of Wisconsin, Vol. IV, p. 548.

That the waters of the region, in certain cases at least, carry zinc in appreciable amounts has been shown by Hillebrand.[1] In water from two springs on Shoal Creek near Joplin, Mo., some distance from any mine, he found 297.7 parts per million of zinc, calculated as sulphate.

The general underground circulation of the region is downward over the central upland, outward from it, and upward in the peripheral region. This does not exclude upward-flowing waters in the Central region, where there are suitable channels and sufficient head. Neither does it exclude simple downward- and outward-flowing waters. Much of the water which falls on the central upland finds its way into the deep bounding valleys of the Osage, Missouri, Mississippi, and White rivers through the surface streams. A second important portion passes through the rocks, but does not necessarily pass below the level of the river valleys mentioned. However, according to the law that waters in their course utilize the entire available cross section, a third portion must be supposed to pass deep into the underlying rocks and, in so far as it reaches these valleys at all, it must ascend in the last portion of its course.

On the west of the Ozarks there is no deep bounding valley. The water which passes down the dip under the impervious Devono-Carboniferous shale finds outlet through the pore space of the rocks or along fractures. Probably it does both, but transmission along fractures is by far the more important. The general surface in the ore-bearing district of the Southwest lies 500 to 700 feet below the central upland of the Ozark region. The waters which have their source in the latter region are accordingly under a pressure in this district sufficient to bring them to the surface wherever there is a suitable outlet. They are confined above by the shale. This forms a close impervious stratum separating the Cambro-Silurian beds, which form the surface rocks over the central upland, from the Carboniferous limestones, which flank the upland on the west. The circulation within the Cambro-Silurian is practically limited below by the pre-Cambrian crystallines. Some of the water doubtless penetrates to the extreme lower limit of the zone of fracture, but there are no good reasons for believing that in this district the amount which passes below the base of the clastic rocks is important.

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[1] Am. Jour. Sci., 3d ser., Vol. XLIII, pp. 418-422.

At an earlier period in the history of the region the shales and sandstones of the Upper Carboniferous undoubtedly formed the surface material over much of the western portion of the Ozark Plateau. The limestones of the Mississippian then cropped out only in a belt around the western end of the dome, as they do now around the eastern end. A portion of the waters falling within this area of outcrop made their way down along the dip under the overlying shales of the Coal Measures, just as similar waters still make their way through the Cambro-Silurian beds under the Devono-Carboniferous. The overlying Coal Measures shales have now been very largely cut away, so that this upper circulation is not so important as it was in former times. A certain amount of the ground water of the region undoubtedly still travels by this course. To a very considerable extent the Carboniferous limestones themselves act as a retaining cover. The water derived from them is believed to be less important in amount and effects than that which flows beneath the Devono-Carboniferous shale.

At present the ground water within the district is fed mainly from two sources: (*a*) From the waters in the Cambro-Silurian beds, having their source over the central upland and being for the district ascending; (*b*) from local rainfall, being that portion of the rainfall which sinks into the ground, and being for present purposes essentially descending waters. Descending waters are dominant above the level of ground water. Below the level of the ground water, and particularly below the level of the streams in each vicinity, they are less important. In the mines the generally uniform amount of water pumped, regardless of seasonal changes, indicates that the ground water is fed mainly from distant sources by means of the deeper circulation. Artesian conditions are common throughout the district. At Fort Scott, Kans., a short distance northwest of the mining district proper, the water rises 5 feet above the surface. At Columbus, Kans., to the west, it rises nearly to the surface. While there are no spouting wells immediately within the area, there is a steady pressure of the water from below, as is shown by pumping operations and the number and disposition of the springs. This pressure from below was sufficient to maintain the level of permanent underground water very close to the present surface up to the time extensive pumping became common in the course of mining operations. There is a belt of variable and irregular width below the ground-water level within which the deeper and the surface waters contend for supremacy, and this is the belt in which the majority of the largest and richest ore bodies occur. Above ground-water level the ore bodies are marked by one set of characteristics, those distinctive of superficial alteration and oxide enrichment. In the zone of mingled waters there is a second set, sulphide ore bodies secondarily enriched. Below the zone of mingled waters still a third sort of ore body is found—that which marks the first or original concentration of the ore. These types of ores have been described already.

ORIGINAL SOURCES OF THE METALS.

The close association of the ores with the underground circulation indicates that the waters must have traversed rocks capable of yielding the metals. A study of the geologic history of the region determines that the lines of underground circulation have remained substantially unchanged since some time in the Tertiary at least. We must believe that while the ores were being formed the conditions were essentially the same as at present obtain over the region. The waters which now circulate underground in the Ozark region traverse the limestones and cherts of the Carboniferous, the sandstones, limestones, and dolomites of the Cambro-Silurian, and in some small amount the granites and porphyries of the pre-Cambrian. The waters which deposited the ores doubtless traversed the same rocks.

Large-quantity analyses of the rocks of the region by Robertson show the presence of minute but important amounts of zinc and lead in the pre-Cambrian, Cambro-Silurian, and the Carboniferous.[1] Analyses by Weems[2] show that the Ordovician rocks of the Dubuque region also carry minute quantities of these metals. Along the west slope of the Appalachians and throughout the Mississippi Valley there are occasional occurrences of both lead and zinc. There is, accordingly, reason for believing that the waters might have taken the metals from any of the rocks of the region. This conclusion is reenforced by the field relations of the ore bodies, as will be later shown. It remains to determine which set of formations actually furnished the bulk of the supply.

It has already been shown that the chemical reactions which have taken place in the course of the segregation of the ores are those which especially characterize dilute solutions. The close relation existing between the richness of the ore body and the probable amount of water which has been active at a given point has also been pointed out. We must believe that there is a quantitative relation between the circulating waters and the amount of ore, and that the ore bodies are the results of the general, rather than of some minor portion of the circulation. They are derived, in the greatest part at least, from those formations through which a large amount of water has passed. Van Hise has shown that if as much silica be deposited in a cavity as issues at the surface it is still necessary to assume that when a cavity becomes filled with silica an average of 100,000 times as much water has passed through the cavity as would fill it.[1] The amount of lead and zinc in solution in spring waters has been very rarely determined. Hillebrand's analysis has already been noted. He suggested that the waters in the particular case were of shallow circulation, and that the unusual amount of zinc found was due to local conditions. Peale[2] gives the quantity of zinc, measured as the sulphate, in 13 cases. It may be assumed that the spring waters carried somewhat more than the average, since in the remaining 803 analyses zinc is not reported, or is given merely as a trace. In one instance 0.01 grain per gallon was determined as bicarbonate. Peale's determinations may be accepted as the best approximation toward average conditions available. The amount determined as sulphate by him was, approximately, 0.01 per cent of one ten-thousandth part. If all of this is supposed to be precipitated as the sulphide, it would require in round numbers 20,000 times as much water to pass through a given cavity as would fill it before the cavity would be closed by precipitation. If, accordingly, the metals be present and the conditions for solution favorable in those rocks through which the bulk of the waters pass, the larger amount of ore will be derived from them. If these rocks are a sufficient source they are inherently the most probable source. The thought may suggest itself that the small amount of water passing through the pre-Cambrian crystallines might, because of a greater abundance of material found there, or because of conditions more favorable to solution, be the source of a relatively great amount of ore. It is not certain, however, that the pre-Cambrian rocks are any richer in lead and zinc than those of the Cambrian and later, and in this immediate region the conditions for solution were probably less favorable in the deeper rock.

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[1] Missouri Geol. Survey, Vol. VII, 1894, pp. 479-482.

[2] Iowa Geol. Survey, Vol. X, p. 567.

The major circulation of the region is through the limestones of the Cambro-Silurian and of the Carboniferous. Robertson's analyses indicate that both contain minute but sufficient quantities of zinc and lead. The facts of the field bear out the conclusions drawn from the analyses. It is a matter of common observation throughout the Mississippi Valley that limestones contain minute quantities of various metallic sulphides.[3] The association of lead and zinc ores with limestones throughout the world is very close and has often been commented on. Limestone, however, has been used to include both magnesian and nonmagnesian rocks. In literature the distinction between the two sorts of rock has not always been preserved. It is probable that the association is more common with the dolomite than with the nondolomitic rocks.[1] If it were possible in every case to determine just what sort of rock was included under the term limestone, the association of the metals with the magnesian rather than nonmagnesian rocks probably would appear much closer.

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[1] Some principles: Trans. Am. Inst. Min. Eng., p. 56.

[2] Bull. U. S. Geol. Survey No. 32.

[3] Iowa Geol. Survey, Vol. X, pp. 569-570.

In the Mississippi Valley the close association of the metals with dolomite and magnesian limestone is very marked. The large ore bodies of the Southwestern district, it is true, occur in nonmagnesian limestones, but they are everywhere associated with dolomitization of the country rock. The association of the ores of that district with dolomite has been frequently noted. As pointing to the source of the water which deposited them there, it may be stated that, in the district in general, wells penetrating the Cambro-Silurian yield water notably charged with magnesia, while wells in the Carboniferous limestone do not.[2] In practically every instance where the ores are mined dolomite occurs, either in intimate mixture with the ores or in the immediate vicinity of the ore bodies. Nowhere in the Mississippi Valley are zinc and lead ores found in quantity where there is not evidence of more or less dolomitization. Very generally throughout the valley lead and zinc are found in the Cambro-Silurian series, which is often so magnesian as to be called the Magnesian series. The amount of mineral found in these older rocks is not always sufficient to constitute an ore. In the Niagara of Iowa small amounts of galena and blende are commonly found, and from Jones County some 4,000 pounds of the former are said to have been shipped. In the Ozark region small amounts of lead and zinc are found in practically every county where the Cambro-Silurian is exposed, and in the Central, Southeastern, and North Arkansas districts important ore bodies occur in these formations. It would seem, then, more probable that the underground waters derived their supply of the metals from the Cambro-Silurian rather than the Carboniferous. There are certain lines of evidence which confirm this conclusion.

It has been pointed out that at an earlier period the circulation of waters down the back slope of the Ozark dome in the Carboniferous limestones was more active than at present. It has also been shown that the Carboniferous limestones have been almost completely recrystalized, and that in part at least the older or white chert has been developed in them by replacement. It has been emphasized that these changes occurred before the development of the ore bodies and were apparently wholly independent of the processes which developed the latter. There was a far-reaching and long-continued circulation in the Carboniferous which brought about many changes in the limestones and cherts of that formation. So long, however, as there was no connection with the deeper circulation of the Cambro-Silurian, neither dolomite nor ores were developed. The same phenomena is shown in the fact that in the Mississippian limestones outside of the Southwestern district, in areas where connection with a possible circulation below has never been established, there is the same recrystallization of the limestone and development of chert nodules and concretions, but no ore or dolomite. So long as the circulation was confined to the Carboniferous rocks there was no deposition of ore. Since the greater flow of water which produced the ore bodies was in the Carboniferous and the Cambro-Silurian and the ore did not come from the former, it must have been derived from the latter. The evidence points accordingly to the ore having been derived in the main from the Cambro-Silurian.

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[1] Iowa Geol. Survey, Vol. X, p. 573.

[2] See Analyses, Rept. Arkansas Geol. Survey for 1891, Vol. II, 1894, p. 19 et seq.

There is yet another line of argument which bears out the assumption that the ores of the Southwestern district were derived mainly from the Cambro-Silurian. It has been shown that the general circulation is downward in the area of the Cambro-Silurian, outward under the Devono-Carboniferous, and upward into the Carboniferous limestones. In the early portion of their course the waters are accordingly traversing the rocks of the Cambro-Silurian, and it is the earlier portion of its course that underground water is most active as a solvent. The exceptions are where temperature and pressure conditions foreign to this region prevail, or where changes in the sort of rock traversed are important. The waters falling over the central upland are oxygenated and so are prepared to change sulphides to sulphates, which are readily soluble. Other reactions are possible, but there are many reasons for believing that this has been the prevailing and most important one. The sulphates are taken into solution by the underground waters and carried westward and finally upward to the point of deposition. The long portion of the course is in the Cambro-Silurian. There is accordingly every opportunity for the waters to take up all their load of any soluble matter present. Deposition becomes important as soon as they meet reducing agents. This is when the water leaves that formation, as is shown by the ores at Granby and elsewhere in the Devono-Carboniferous. At the very first contact with the organic matter widely distributed through these shales deposition occurred, and the inference is that the solutions acquired their load of the metals in the course of their journey in the Cambro-Silurian.

The Cambro-Silurian rocks are largely dolomitic and magnesian and, according to the rule noted above, that lead and zinc are commonly associated with magnesian rocks, the derivation of the Ozark deposits from them was to be expected. The reasons which may be assigned for the association of lead and zinc with magnesian limestones are to some extent theoretical. It has been common to consider the association due to wholly secondary causes. Dolomite is a porous rock and hence is open to the circulation of underground waters. Its homogeneity causes it to fracture in extensive planes and so trunk channels of circulation are opened through it. It is open to wide circulation of underground waters and particularly susceptible to changes which come from the circulation of water in rocks. It is a rock which may readily be believed to selectively absorb ores from a solution coming from any source. It is particularly subject to metasomatic replacement. In the case of the Southwestern district, however, these reasons can not be valid, since the ores are here deposited in nonmagnesian limestones and their association is with waters derived from magnesian limestone rather than with a dolomitic rock itself.

The first suggestion is that a close chemical relation exists between magnesia and the metals concerned, but of this there is no good evidence. It is true that magnesium salts in solution balance salts of these metals, but this is a common relation between many elements. The very widespread presence of lead and zinc compounds in magnesian limestone strongly suggests that the original introduction of the lead, zinc, and magnesia in the rocks was simultaneous and doubtless dependent upon chemical interactions. The exact nature of this relation is not understood and can be determined only by an exhaustive investigation. After the three materials had been deposited in the rock, however, the law of mass action accounts for their common transportation and segregation. The constant association of the three leads to the hypothesis that the association is primary and due to the fact that the conditions under which large areas of dolomitic rock are formed are favorable to the primary deposition from the sea of minute quantities of metallic sulphides. This hypothesis has been elsewhere developed,[1] but may be outlined here.

In the Dubuque, Iowa, district the Galena-Trenton formation includes a partially dolomitized series of limestones. Dolomitization extends irregularly from the top downward and is regional, not being associated with definite cracks and water channels, as in the Joplin region. It occurred very early, seemingly immediately after the limestone was deposited, if not during the deposition. There is evidence that the rocks were formed under shallow-water conditions, but in the portion dolomitized there is no evidence of nearness to shore. These facts suggested the hypothesis that the dolomitization occurred as a result of reaction between the magnesium of shallow sea waters, concentrated most probably by evaporation, and the newly formed limestones below. This reaction is known to occur under such circumstances. Spurr[2] observing similar conditions in the Aspen district and working independently has developed the same explanation. Willis[3] has shown that the Cambro-Silurian rocks of the Appalachian region accumulated in an extensive mediterranean sea of warm shallow waters and that chemical precipitation was probably very important in this sea.

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[1] Iowa Geol. Survey, Vol. X, pp. 573-575.

[2] Mon. U. S. Geol. Survey, Vol. XXXI, pp. 11-13.

[3] The Appalachian region: Maryland Geol. Survey, Vol. IV, Pt. I, pp. 47-49.

In the Dubuque district, except where they have been transported by downward-flowing waters, the ores are confined to the dolomitic rock. Certain peculiarities in the localization of the ore deposits are there explained by the hypothesis that the concentration of sea waters which produce deposition of magnesia was also an important factor in producing deposition of metallic sulphides. It is known that in the sea minute quantities of the metals occur and from sea water so concentrated it is believed that they would be precipitated in minute quantities. This precipitation may have been brought about by direct chemical precipitation in certain cases. That is, the waters may have become so concentrated as to pass the point of saturation. This is not, however, believed to be probable. Fuchs and De Launay have calculated[1] that such precipitation would require the evaporation of 49,000 kilometers of sea water per square meter of surface in order to produce a layer of zinc sulphide 1 centimeter thick. It is not necessary, however, to assume any such extreme conditions. Deep sea dredging has shown that reduction of various salts to sulphides is widespread along the sea bottom. It is to be noted that any peculiar and local conditions producing an excess of reducing agents would be effective in proportion to their concentration. Chamberlin has argued, that in the lead and zinc districts of the Mississippi Valley, seaweeds have been concentrated in the eddies of ocean currents.[2] Blake also has suggested the possible local submarine exhalation of hydrocarbons as gas or oil,[3] but for this suggestion no evidence is presented.

Whether the general hypothesis outlined is applicable in the Ozark region can not be determined without further study of the rocks of the Cambro-Silurian. The latter are strikingly like the rocks of the Upper Mississippi region in many particulars. While the conditions under which the rocks of the Ozark region were formed are not yet fully known, it is significant that in the North Arkansas region there are evidences of shallow-water deposition in the midst of the series. Whatever may prove to be the correct reason for the association of the metals with the Cambro-Silurian, the phenomena of the field warrant the unequivocal statement that in the Southwestern district the major portion at least of the metals has been derived from those beds.

CONCENTRATION OF THE ORES.

The metals as originally precipitated from the Cambro-Silurian sea were thoroughly disseminated. It has been the work of underground waters to gather this disseminated material together. The resulting accumulations are ore bodies. Many of these ore bodies have been in turn torn to pieces as a result of changing conditions or the general advance of erosive forces downward. The metals have been carried away only to be redeposited in a different locality or at a deeper horizon. Concentration has followed concentration and the ore bodies now worked are the net result of a long series of processes. It is impossible to follow all these changes in detail. The general chemical process has already been outlined as one of oxidation of sulphides, transportation as sulphates, and precipitation as sulphides. As the waters were gathered into trunk channels of circulation larger quantities of metals were brought together, and in the course of long-continued movement of water along such a channel conditions favoring precipitation would bring about deposition of very considerable bodies of ore.

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[1] Traité, etc., Vol. II, p. 373.

[2] Geology of Wisconsin, Vol. IV, p. 530.

[3] Trans. Am. Inst. Min. Eng., Vol. XXII, p. 629.

The principal condition producing precipitation in this region was the mingling of solutions, and in particular the meeting of the sulphate solutions with various reducing compounds derived from organic matter. This has been the principal reducing agent throughout the region. Evidence of its action is particularly clear in the Southwestern district. Organic matter is present in the limestone, in the overlying Coal Measures shale, and in the underlying Devono-Carboniferous shale. In the form of bitumen it is widespread. Bitumen readily breaks down into a number of compounds which are reducing in action. As a result of diffusion and movements of the solutions themselves, these compounds are widespread throughout the ground water, even where masses of bitumen itself are rare. Sulphate solutions, accordingly, on coming into the Carboniferous beds either from below or above are promptly forced to deposit as sulphides the metals which they carry. Other series of reactions doubtless occur and have been important locally, but the general process has been the one outlined.

LOCALIZATION OF THE ORE BODIES.

In the Cambro-Silurian strata the localization of the ore bodies is dependent mainly on the presence of suitable conditions for deposition, since the circulation of ore-bearing waters is widespread and general. Crossing of fissures, by allowing a mingling of solutions, favors deposition. The presence of an impervious shale, particularly if it be charged with organic matter, has a like effect and, in general, an essential factor is the presence of suitable reducing agents.

In the Carboniferous rocks the first condition is the presence of fractures deep enough to cut the Devono-Carboniferous and so penetrate the source of supply. It is as yet unproved whether in the Joplin region the stresses which produced these fractures were more important than elsewhere. The shale is thinner and of such a nature as to be more easily broken, so that here stresses would break the shale and produce fractures across it which elsewhere would give rise to slight monoclinal folds only.

Within the Carboniferous, open ground, whether as the result of fracturing or solution, or both, was important in affording a place for the deposition of the ore. Open ground is, however, widespread, as is also the presence of suitable reducing material.

The impervious stratum has been very important in the Southwestern district, not only in directing the course of the waters, but in producing actual deposition. This is shown in the widespread occurrence of ore in the base of and immediately under the Coal Measures shales. It is also instanced in the common occurrence of ore against bars or ribs of hard ground in the midst of broken and open ground. The reasons for this are not altogether clear, though the facts are patent. In part it is doubtless due to the bars representing the sides of fault blocks, and hence denoting proximity to a source of supply. In the case of the shales the local presence of an excess of organic matter is doubtless important. In other cases it is probably due to indirect chemical action. The bar, by offering to the solution an excess of some soluble material, disturbs the equilibrium in the solution and produces deposition. In any case the bar or impervious stratum, by reason of its greater density, checks the flow. While this factor may be important in the case of ore deposits made against shale, the reducing action of the solutions furnished by the shales is the dominant factor. Solutions commonly penetrate the shale for some distance, and pebble ore is found in them for 10 or 12 feet or more from the contact. Mingling of solutions would also be important along a bar, since no material is wholly impervious, and a certain amount of water must be supposed to come through the bar, meeting at the contact with the open ground the waters of the latter. Possibly also eddies are occasionally formed at such a contact and promote precipitation by bringing about a more thorough mingling of the solutions.

SECONDARY CHANGES.

The explanation of the genesis of the ores given above applies particularly to the ore bodies of the first concentration. The fact that these ore bodies have since been extensively altered and perhaps repeatedly reconcentrated has been dwelt on in some detail elsewhere. Secondary enrichment has been very important in the Southwestern district especially, and the large bodies of blende there worked are largely the products of both ascending and descending waters. The fact is to be recognized, however, that the original ore bodies were in many cases very rich, and that in the large majority of them blende was originally dominant.

SUMMARY.

The hypothesis of the genesis of the ores of the Ozark region here offered is applied particularly to the Southwestern district and involves the following steps:

1. Original precipitation of the metals from shallow seas by organic matter, perhaps assisted by concentration of the solution through evaporation at the time of the formation of the dolomites and magnesian limestones of the Cambro-Silurian.
2. Concentration by the action of ordinary underground water with deposition, through mingling of solutions and the presence of organic matter.
3. In the Southwestern district this deposition took place in the Carboniferous limestones in fractured and brecciated areas, where the solutions, coming along fault and fracture planes from the Cambro-Silurian limestones below through the Devono-Carboniferous shale, met waters circulating in the Carboniferous limestone and charged with organic matter.
4. Alteration by superficial agencies, with the result of a change of sulphides to carbonates, silicates, etc., the production of an orderly vertical arrangement of the ores, and the frequent notable enrichment of the ores above water level and for a limited distance below.

CHAPTER IX.

By H. F. Bain.

GUIDES FOR PROSPECTING AND METHODS OF MINING.

The geologic study of the region allows certain inferences to be made which is hoped may prove to be of value in prospecting and in following out ore bodies already located. There is naturally no improvement to be made on the ancient rule to follow the ore, but when this is not possible or easy, certain phenomena associated with the ore may have sufficient significance to determine the proper line of prospecting. In the following suggestions lines of probability only are pointed out. Every rule has exceptions, and this is especially true of rules for prospecting. Much must always be left to the experience and judgment of the men in immediate charge, and in the Ozark region the local miners have proved themselves exceedingly capable. The district is peculiar in many particulars, and good mining men trained elsewhere very often make mistakes when first coming into it. This is especially true in the Southwestern district. It is to the latter district that this chapter applies, except where specific reference is made to other districts.

CLASSES OF ORES AND CHARACTERISTIC FEATURES FOR THEIR DISCRIMINATION.

It has already been shown that the ore bodies of the Southwestern district belong to the general class of ores which have been concentrated, first, by ascending waters, and, secondly, have been modified and reconcentrated by descending waters. From this knowledge of their genesis it is possible to draw certain inferences with regard to their extent and permanence, which are very important in determining the proper methods for their exploration and development. So far as the concentration is a result of downward-moving waters, it is unfavorable to permanence in richness and extent with depth. So far as ascending waters have produced the ore bodies, the conditions for permanence in depth within limits later discussed are favorable. In this region it is not always easy to distinguish the action of the two sorts of waters. Descending waters are normally oxidizing waters, but in the Joplin region the constant pressure of water from below limits their penetration, and the wide presence of reducing agents obscures their action. There are, however, many cases in which they clearly have been important factors and many others in which they probably were. In the typical instance of the action of the descending waters in the Joplin region the ground is soft and open from the surface down. Occasionally there is an overlying cap of hard rock, the shaft in that case being at one side of the channel of communication with the surface. Galena is in such an instance the first ore encountered. Normally it is in a rich pocket, associated, perhaps, with zinc silicate or carbonate and with red clay for gangue material. Below the galena, and usually where the red clay gives way to drab or black selvage, the zinc carbonates and silicates are replaced by blende, and usually at the same place the underground water level is encountered. The blende then becomes dominant and the galena very subordinate. Such an ore body usually is the product of sulphide enrichment, as already described. It may be expected to persist in depth to the limit of the action of the surface waters only. Below it there is, in many cases at least, an increase in the relative amount of iron sulphide present, though in this district blende more commonly retains its dominant position so far as yet tested. Drill records at Granby show that there, as is commonly true in other regions, the iron pyrites in turn becomes dominant with depth.

Below the zone of dominance of iron pyrites, or in its absence below the horizon of the rich bodies of blende, are the original ore bodies, or those resulting from the first concentration. Wherever, because of a protecting cover, of a dominant upward flow of the deeper-seated waters, or of any other cause, the ore bodies have been protected from the action of descending waters, the ores of the first concentration occur. It is only in the instances where the two circulations have operated that the full vertical sequence is found, viz, (*a*) gossan, or surface ore resulting from oxide enrichment; (*b*) enriched sulphides; (*c*) ores of first concentration.

The ores of the first concentration have already been described. The fact that in many instances, at least in the ore as originally concentrated, the blende was dominant makes it sometimes difficult to distinguish these ore bodies from those in which there has been more or less secondary enrichment. The ores of the first concentration may be expected to retain their character and richness to their final limit in depth. They yield more steadily, though rarely as well as do the ores of the upper ground. This fact has been recognized by the miners and generalized in the statement that hard-ground mines are normally less rich but more permanent than soft-ground mines. Hard-ground mines are usually, though not by any means always, in ores largely produced by a first concentration.

While the action of descending waters has been normally to soften and enrich the ground, this is not always the case. Enrichment below may mean impoverishment above, as is excellently shown in the case of the Boston Get-There mine, already cited. Usually the ore which served to enrich the lower ore bodies has come from a former upward extension of the ore body removed by erosion, and, consequently, the essential result of the process as a whole is enrichment.

The most constant accompaniment of descending waters is oxidation. This shows itself in the reddening of the soft clayey matrix. Where red clays are found evidence of descending waters is complete, and any peculiarities of richness or association of ores found in them may be expected to disappear as they do in depth. In the presence, however, of an excess of reducing matter in the Carboniferous limestone, descending waters may be active and yet not show in oxidation of the iron or in production of red color in the clays. An example of this is shown in fig. 38, representing a specimen from the Why Not mine, in South Joplin. The big cubes of galena here have been dissolved and rounded, while the sharp-pointed dolomites have not been touched. Such action, so far as we know, could be brought about only by oxidizing waters, and in the mine there is independent evidence of their presence, in the softening of the ground and in a fairly clear connection between the waters of the mine and the surface. At the same time there is very little red clay in the mine, the excess of carbonaceous material holding the iron in the carbonate form, according to the law of mass action.

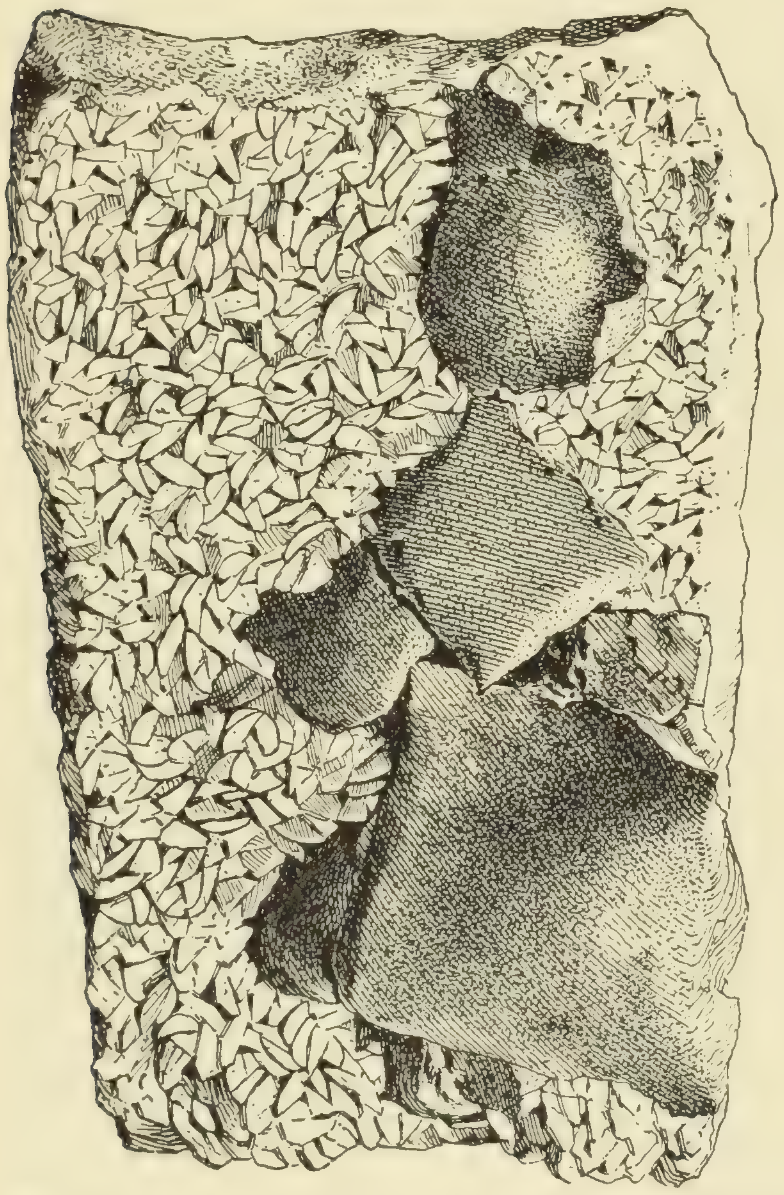
FIG. 38.—Galena, rounded by solution, on unaltered dolomite, Why Not mine, Joplin, Mo.

The very general presence of practically clean galena in the upper levels and similarly clean blende below leads to the belief that concentration by downward-moving waters has been widespread, even though plain cases of oxidation are relatively rare. Surface alteration shows also in the change in the character of the ore. Silicates and carbonates are wholly the result of the action of surface waters and will give place in depth to sulphides, or the individual deposit will cut out when their limit in depth is reached.

PROBABLE LIMIT OF DEPTH OF MINING.

Enrichment as a result of the action of surface waters can not be expected to continue with depth. In the Boston Get-There it is important to a depth of 200 feet. Below that there has been little opportunity for study. The main activity of surface waters will doubtless be found confined within the first 200 feet of the surface in this district.

The depth to which the ore bodies formed by ascending waters may be expected to continue is dependent on several factors. The mines now worked are practically confined to the upper 200 feet of strata. It can not be said that they show any general increase or decrease in value with depth except where secondary action is important. There are more shallow mines than deep ones, but this may be an expression of the fact that the deeper beds have been less prospected rather than that there is actually any less ore present. Below the depth of present workings the conditions are known only through studies of the stratigraphy and drill records.

Ore has been reported from drill records to a depth of 1,000 feet,[1] and while the number of drill holes carried to that depth are too few to warrant any judgment as to the quantity of ore occurring, the mere fact of its presence has some significance. The writer has personally examined drill records and samples showing ore in the magnesian limestones at a depth of 500 feet. So far as the mere samples showed, these ore bodies were of workable richness, but not enough holes had been put down to determine the size of the ore body. Ore has been found by drilling at several points in and immediately below the Devono-Carboniferous shale. At Granby ore is commonly found at this horizon, and so far as can be judged by drill samples the ore is quite as rich as that now being mined. From what we know of the conditions it is not improbable that a run may be developed at this horizon. That such a run is general has not yet been demonstrated, and one would need to be very cautious in seeking to develop it.

The general stratigraphy of the region affords the best answer to the question of the probable permanence of ores with depth, and it indicates that mining will in all probability be mainly confined to the beds above and within a few feet of the Devono-Carboniferous shale. It is in these upper beds that the most favorable conditions for the deposition of large and rich ore bodies obtain. It is here that there is the largest amount of reducing material. It is also in these beds that fracturing and solution have been most important, so that ore-bearing solutions were able to penetrate widely and mingle freely. It is true that the beds below the shale are ore bearing in Central and Southeastern Missouri and elsewhere, but until we know more of the conditions in these other districts we are not warranted in assuming even the probability of the same beds yielding ore in the Southwestern district.

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[1] Crossman, Drill chart: Mineral Industry, Vol. VIII, 1899, p. 667.

Certainly any assumption that the ores will get richer in depth because near to the original source is wholly unwarranted. The evidence favors the belief that originally the metals were widely disseminated, and accordingly the nearer we get to the source the poorer the ore will be.

Within the beds above the dividing shale the best opportunities for ore are in the strata above the heavy chert. The limestone below, as has been stated, does not break up so widely or so readily, and accordingly is not so favorable for the formation of large ore bodies. These beds, however, have not been as yet thoroughly explored, and while the conditions for large ore bodies are not so favorable in them as in the beds above, it is to be expected that they will yield considerable ore at least.

In planning works and making investments it is well to keep in mind the probability that the mining will, for a long time at least, be confined to a variable thickness of strata having, so far as known, a maximum depth of 500 feet and a probable average depth of 400 feet. Some ore will be found below these depths. It is possible that a few large bodies may be so found, but this is quite uncertain, and it is unwise to count on it in purchasing or developing properties. The large and rich bodies of galena and blende which characterize the region are doubtless practically limited below adjacent to the Devono-Carboniferous shale. The conditions in the Cambro-Silurian country are so different and the time devoted to their study was so limited that it is not thought wise to express an opinion with regard to them.

EXTENSIONS OF THE AREA.

The limits of the productive area in the Southwestern district are manifestly the limits of the area over which the conditions favored the formation of the ore. The most important limiting condition seems to have been the absence of deep-seated fractures. Until the detailed mapping shall have been carried over the region it will be impossible to express a decided opinion as to whether notable extensions of the area are to be expected. It is to be remarked that so far all the important camps are located at points where some ore at least was found at the earliest settlement of the country and that the newer discoveries have been rather within the limits of these camps than between them.

GUIDES FOR PROSPECTING.

TOPOGRAPHY.

Miners are accustomed to pay close attention to the relations of ore deposits to the topography and, while this frequently is pushed to an unwarranted degree, there are substantial reasons for following the topography in certain particulars. In the Ozark region topographic guides may be helpful in determining three things important in connection with the ore bodies. These are: (*a*) zones of fracture, (*b*) zones of secondary concentration, and (*c*) blanket veins.

Probably the most important aid which topography can give to the prospectors is in locating lines or zones of fracture. It is important in prospecting to locate the fractures and particularly the broader zones of fracture, since these are the belts along which the major underground circulation has taken place and where mineralization is accordingly most likely to occur. Aside from the opportunity which valleys afford to examine exposures and hence determine the matter by direct observation, the valley is itself very often the expression of a line or zone of fracture. It has been customary in recent years to emphasize the influence of hard and soft strata and general structural features in determining the location of valleys. Outside of the glaciated areas the influence of fractures and zones of crushed rock seem, however, to have been equally important, especially in horizontal rocks. This is particularly well exemplified in the Joplin region, where at least many of the streams follow lines or zones of fracture Center Creek between Webb City and Cartersville, and the valley extending from Prosperity northwest to Cartersville are examples. The linear and rectilinear character of much of the drainage indicates apparently that the streams commonly follow these zones of fracture. Not all the fracture zones are marked by surface depressions, since in many cases the rock has been so thoroughly recemented that it is not notably more open than the surrounding rock. Where the zones of fracture are under divides determined originally by any other factor there is less tendency for the present surface waters to hunt them out, and as a result they are less apt to be resoftened by underground water. An important subsidiary factor in bringing about the location of the streams over the zones of fracture is the fact that the faulting which accompanied the fracturing often dropped the softer shales of the Coal Measures down below the general surface of the limestone. As a result, fracture zones present not only a zone of fractured rock to underground waters, but a surface belt of softer rock as well.

Secondary concentration, especially in the form of oxide enrichment, being the result of surface waters, stands in close relation to topography. In the Southwestern district it is a common but not invariable rule that the largest and richest ore bodies are found in depressions, and of these depressions the shallower side valleys, or "draws," as they are called, are more favored for prospecting. This rule is empirical and has been handed down from the earlier days, when shallow deposits of galena in particular were sought after. Later developments have tended to a certain extent to prove that deeper bodies of ore are not so closely related to surface topography. Important ore bodies have been found well up on the highest divides of the district, though it is notable that, as a rule, such ore bodies are deep and are in hard or sheet ground. It has also been proved that ores are found in the very bottom of the main valley of the region, that of Spring River. This valley was for years considered unfavorable ground for prospecting, but the Lehigh and Riverside mines effectually prove the older idea to be not well founded, since mining is now carried on under the river itself. It remains true, none the less, that much ore has been developed by following the simple miner's rule to prospect the slopes of the smaller valleys. One of the reasons for this seems to lie in the fact that the sides of the valleys are the most favorable places for concentration by surface waters and as erosion goes on and the land level is lowered, more and more of the ore is concentrated in such situations. Chamberlin, in his studies of the Wisconsin mines, was the first to point out and explain this, and the principle is one apparently of wide application. Excellent examples can be seen throughout the Ozark region.

Topography in connection with the structure is an excellent guide in following blanket veins. When the beds are undisturbed they may be traced by simply following the topographic contours. Where folding and faulting occur, dip and displacement must be taken into account. In the North Arkansas district blanket veins seem likely to prove important. In the Southwestern district none of the blanket veins, or sheet deposits, as they are there called, are near enough to the surface to be exposed by erosion, and accordingly topography is not important in this connection. In the vicinity of Prosperity, Mo., it is notable that as the ore is followed away from the valley and under the divide the bodies assume very commonly the sheet form, but this is the expression of the fact that commonly the divides mark the harder and less broken ground.

STRUCTURE.

Aside from the general structural features of the region, which are suggestive in locating the ores, there are certain detailed features which are extremly significant. The ores are found in those portions of the rock through which the waters either now circulate or have circulated. In general this means the soft broken or crushed ground. Occasionally it means ground which has been broken but in which the processes of cementation have gone so far that the ground is now thoroughly firm and hard. In the soft or "open ground," as it is known to the miners, the ore solutions may wander widely and the ore bodies are extremely irregular. In such ground prospecting must be thorough, and there is very little to guide one. There is, however, one very suggestive fact, and that is that the greatest deposition has in such situations taken place wherever the solution came in contact with any considerable surface of hard or unbroken ground; that is, the ores occur most frequently along the bounding line between hard and soft ground. The strips of hard ground are known to the miners as "bars" and these bars may be either areas of unaltered and unmoved country rock or blocks of limestone, flint, or shale faulted into contact with the soft ground. There seems to be very little difference in the deposition of the ore around shale, flint, and limestone, except in the form which it takes. When the contact is with shale the usual result is a partial impregnation of the shale and the development of pebble ore. In the case of limestone there is usually a dolomitization and a partial metasomatic replacement of the rock by ore. In the case of flint there is little ore in the hard ground itself except in the form of sheet ground. In any case the main ore is found in the broken ground near the bar. This is an empirical rule. The reason for it is not altogether clear and has been already discussed. Whatever the explanation of the phenomena may be, the experience of the field indicates that in the case of soft ground the prospects are better for finding ore along the edge of bars than elsewhere.

A particular instance of the bar or impervious stratum, which is of wide importance, is the concentration which commonly takes place in the base of and under the patches of Coal Measures shales that are found throughout the district. Shale is a very impervious rock. Underground waters coming against it largely turn and pass along the contact between it and the other rock instead of passing into the shale. Under such circumstances the shale acts as do other bars, and, as a result, ore is commonly deposited under overlying shales where the waters are ascending and on them where waters are descending. In the Southwestern district Coal Measures shales formerly covered much if not all of the district. The first concentration of the ores was brought about by ascending waters and probably began before the overlying shale was much if any cut away by erosion. The result was that considerable bodies of ore were formed at the base of this overlying shale. Where the shale remains these ore bodies have been at least partially protected from surface waters and accordingly ores are commonly found under and around the edges of these small outlying patches of shale. Where the shale has been removed by erosion the ore originally deposited under it has been attacked by the surface waters and either reconcentrated by the process of residual concentration, altered to carbonates, silicates, etc., or perhaps carried off in solution to be redeposited elsewhere as a secondary ore body or a secondary enrichment of an earlier or of the same ore body.

A second important reason for the association of ores with the outliers of Coal Measures material is that these outliers often owe their preservation to having been faulted down below the level of active erosion. In such cases they mark the lines or belts of fracturing and faulting with which, as already pointed out, the ores are closely associated.

RELATIONS OF THE ORES.

The common vertical arrangement of the ores, with galena dominant above and blende dominant below, constitutes a valuable guide in the search for zinc ores. The ores of the Southwestern district as first concentrated carried large amounts of blende, if, indeed, the latter was not actually dominant. When, accordingly, an ore body is found in which galena is dominant, the inference is that the blende has been removed in solution by surface waters and carried elsewhere to be redeposited. Since the general course of surface waters in this district is downward, the blende has, in most instances, been carried in that direction. It may be expected, accordingly, to be found at lower levels, and there are thus excellent reasons for accepting the prospector's dictum that a large body of galena in shallow diggings means usually a large body of blende at or below water level. Exceptions occur, but the general probability is along the line indicated.

The character of the matrix is also an important guide. If the matrix be made up mainly or largely of red clay it means that oxidizing waters have been very active. It is useless to look for blende in quantity, though silicate or carbonate of zinc may be found and galena may be common. When either in depth or lateral extent the red clay gives place to black selvage, blende may be expected to appear and galena to become subordinate.

The associated gangue minerals are to some extent important guides. There has been no considerable first concentration of ores in the Southwestern district free from dolomitization, and in looking for ore the pink spar or dolomite is a very favorable indication. Iron pyrite or "mundic," while not valuable in itself, is closely associated with the ores, and the finding of it is usually favorable. Calcite and barite are to a less extent favorable indications. In the Central and Southeastern districts barite is a much more favorable indication.

RELATIONS TO WATER CHANNELS.

In searching for ore or for the continuation of an ore body in this district it is advisable to study the course of the water channels and to follow them. The ore has been deposited by underground waters and is usually in greatest quantity where the flow has been most important. The greatest flow is along the trunk channels, and the waters move toward and along them. Following the flow along the channels will accordingly bring the prospector into the area where the conditions are favorable for the deposition of ore. When the main trunk channels are found they should be followed in both directions. The course of these channels will usually give the direction of the main belt of fracturing, as circulation is most active along such a belt.

The direction of the flow of water is particularly important in cases where secondary enrichments are suspected. The ores which have been secondarily enriched represent the grand prizes in mining and are usually exceedingly valuable. Secondary enrichment has usually taken place within a single ore body or within a single mass of breccia. Accordingly, it should be possible to find the enriched ore body if the impoverished zone be recognized and the direction of the flow of water be determined. An excellent instance is seen in the Boston Get-There property, already described.

FORM OF ORE BODY.

The form of the ore bodies has already been shown to be exceedingly variable. It is very difficult and unsafe to make calculations on the total yield of an ore body after it has been drilled or partially developed only. The mining methods are unusual in that there is very rarely any attempt to block out ore, and ore in sight, in the technical sense of blocks of ore which may be examined along four sides, is practically absent. It has been found as a general rule, to which there are rare exceptions, that a considerable thickness of ore body is to be correlated with a considerable lateral extent. This is the safest guide to the size of an ore body which drilling affords.

METHODS OF MINING.

No attempt can be made here to discuss in detail the methods of mining and milling which experience has shown to be best in this district. It is desired merely to point out a few particulars in which these methods are conditioned by the form and character of the ore bodies and the geologic conditions under which they occur. Several notable mistakes have been made and much money has been lost by attempting to develop certain mines in this district along lines and by methods used elsewhere where the ore bodies are richer and more continuous and where costs are higher. The methods which have long been used in the Southwestern district are characterized by extreme simplicity and low cost of equipment. While hand windlasses are not now common, horse hoisters and hand jigs are still widely used (see Pl. XXI.) The steam plants, it is true, supply the bulk of the ore. The better plants are models as regards lightness and simplicity, though hardly so in other particulars. The whole system of mining seems crude and wasteful to one accustomed to the larger individual operations of other regions (see Pl. XXII). The experience of many operators throughout the district favors, however, the methods in use, and it usually is a sound rule in mining that methods widely adopted are at least well founded. The cruder and more wasteful plants and those badly managed are not to be imitated, but the simple, cheap, and reasonably efficient plant characteristic of the district is believed to represent the best equipment yet devised (see Pl. XIV, *B*). For the benefit of outside investors not personally familiar with the district the reasons for this belief are summarized below.

The ore bodies of the Southwest are worked mainly for blende. A certain amount of galena—on an average 1 ton to 12 tons of blende—is mined in connection with the zinc ore; but the value of the ore is usually measured in terms of its richness in blende. The ores vary widely in richness, all grades from barren rock to practically clean blende being delivered to the mill platform. The mill runs vary from 4 to 30 per cent—that is, from 4 to 30 tons of blende are produced in milling 100 tons of mine dirt. The 4 per cent ore is, at present prices, about the lowest which can be made to pay expenses for any continuous runs, and at most mills probably nothing averaging less than 5 per cent can be made to pay now. The majority of the mines of the district are probably working on ores running between 5 and 10 per cent. Anything above the latter is regarded as rich. The John Jackson mine is said to have yielded an average of 22 per cent for the three years and more that it has been worked. This is, however, known everywhere as one of the richest mines in the district.

The per cent below which it is not profitable to handle the ore varies naturally with the price of the product, the equipment and management of the mine, and the character of the ore. What such a per cent means may be made clearer by giving the value of such an ore. When blende carrying 60 per cent metallic zinc is selling at $25 a ton, 4 per cent ore of standard grade would have a value of $1 a ton in the mine. Much of the ore, however, is below standard grade, and would bring anywhere from the standard price down to $20 or even less, according to the amount and the nature of the impurities in the ore. The decrease in value with increase in impurities cuts the price very rapidly. At $20 the 4 per cent ore in the mine would be worth 80 cents a ton. Against this value is to be charged the cost of mining, including blasting or timbering, or both, loading, tramming, and hoisting. Milling expenses and milling losses must be added to this, as well as interest, superintendence, depreciation, and repairs. If, as in most cases, the mining is on leased ground, there is a 10 per cent first-lease charge and 2½ per cent pumping charge. These charges are calculated on the basis of receipts from the sale of ore. It will readily be seen that the margin of profit on mining and milling is very small in the case of low-grade ore. The profits which are made come from the large bodies of rich ore occasionally encountered which are easily and cheaply mined. When such a body is found the profits are big so long as the ore lasts. The main mining must be, however, in low-grade ore, and accordingly must be carried on as cheaply as possible. This fact has come to be very generally recognized, and as a result the methods adopted are very simple and inexpensive.

Another essential factor in controlling the cost of production is the irregular or pockety character of the ore bodies. This has, perhaps, been sufficiently illustrated in the preceding pages. The individual ore bodies are rarely large. The mines must accordingly be short lived and the plants must be built to meet that condition. In a district where it is cheaper to sink a new shaft than to tram ore 600 or 700 feet under ground, central shafts of large capacity are out of place. Large central mills to which the ore of a whole tract is brought are not considered a good investment. In hauling 100 tons of 10 per cent ore 90 tons of waste drift is moved, and when simple and effective mills of small capacity are so easily and cheaply built and run, individual mills are to be preferred, even though the larger mill be able to make a slight saving per ton in mill charges. It is difficult to supply dirt steadily enough to keep a large mill running, and loss of time is more costly with a large than a small plant. The higher cost of running individual plants comes largely from the common and expensive method of power generation and distribution. This can be overcome by the development of central power plants.

The mills of the district have ordinarily a rated capacity of 100 tons in ten hours. They are very simple and are developed on the principle of using a rougher jig before cleaning, instead of attempting close sizing. The result is a very great capacity at small cost. The saving is not so close as in a well-run sizing mill, but the extra ore saved by the latter is not in this district worth the added cost of saving it. It is probable that a closer saving will in time be made by a more common use of sand jigs and concentrating tables. A hundred-ton mill can be built in the district at a general price of $6,500 to $7,000, and the opening and equipping of a mine costs ordinarily, approximately, $10,000. The mill can be run by four men. To that number must be added a hoisterman and an underground force. The number of men necessary under ground varies very widely with the character and size of the ore body. Under average conditions the cost of running a mine and mill ranges between $300 and $500 a week. The mill and plant are of such style as to be readily torn down and moved when the particular ore body is worked out, and the whole plant is designed for rapid work. Economy is sought in first cost rather than in refinements of efficiency, and in view of the irregular and uncertain nature of the ore bodies this is doubtless the correct point of view. The whole style of equipment and the methods of mining and milling are designed to meet the conditions of short-lived individual deposits of low-grade ore.

THE ORE DEPOSITS OF THE RICO MOUNTAINS COLORADO

BY

FREDERICK LESLIE RANSOME

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THE ORE DEPOSITS OF THE RICO MOUNTAINS, COLORADO.

By F. L. Ransome.

INTRODUCTION.

Field work in the Rico district was begun on the 1st of July, 1900, with Mr. Alfred Mayer Rock as field assistant, and was brought to a close on the 18th of August of the same year. It was found that work in the larger mines had practically ceased, and that leasing on a small scale and prospecting were the only surviving forms of mining activity. But against this decided disadvantage in a study of the ore deposits were to be set off some factors of direct gain. In 1896, Mr. C. W. Purington, then of the United States Geological Survey, visited the region and made a brief investigation of the ore deposits. The results of his reconnaissance were never published. They indicated that the interest and complexity of the phenomena there displayed demanded a better and larger-scale topographic map than was then available, as well as a comprehensive investigation of the geology of the region. This map was made, and in 1898 Mr. G. W. Tower was detailed to make a thorough study of the ore deposits of the Rico Mountains in connection with the geological work of Messrs. Cross and Spencer. Mr. Tower subsequently severed his connection with this Survey, and his manuscript report was never published.

The notes and manuscripts of Messrs. Purington and Tower, as well as their collections, were placed at my disposal and have been employed to supplement my own observations wherever this appeared necessary. Where their material has been so used it has been credited to its source. The main usefulness of their notes, however, has been to afford starting points from which to plan various lines of investigation in the field. To Mr. Tower I am particularly indebted for a complete set of tracings of such mine maps as could be obtained at the time his work was done and for an excellent collection of the ores of the district. The possession of these has resulted in a considerable saving of time and labor.

The literature of the Rico district is not extensive. A paper by John B. Farish[1] on the ore deposits of Newman Hill and a later one by T. A. Rickard[1] on the Enterprise mine are important contributions and will be frequently referred to in the following pages. The latest and most comprehensive work, however, is the report of Messrs. Whitman Cross and Arthur C. Spencer[2] on the geology of the Rico region. A knowledge of the essential results of their investigation and interpretation of the general geological structure and history is necessary for a proper understanding of the following pages. The present paper is, in fact, a supplement and sequel to their report.

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[1] On the ore deposits of Newman Hill, near Rico, Colo.: Proc. Colo. Sci. Soc., Vol. IV, 1892, pp. 151-164.

Of the mining men of this district it is difficult to speak in terms of merely formal acknowledgment. An experience of some years in Western mining towns has failed to discover such hospitality, natural courtesy, and readiness to further scientific investigation by all means in their power, as was shown, without any exception, by the men of Rico.

GEOGRAPHY.

The region covered by the Rico special map[3] and treated in this report lies in southwestern Colorado, between longitude 107° 58′ 37″ and 108° 5′ 39″ west and latitude 37° 40′ and 37° 44′ 39″ north. Its area is approximately 35 square miles, and its general position is shown by the accompanying index map (fig. 39). Rico, a town of a few hundred inhabitants and the county seat of Dolores County, lies nearly in the center of the district, on the Dolores River, which traverses the area from north to south. The Rio Grande Southern Railroad connects the town with the Denver and Rio Grande system at Durango on the south and at Ridgway on the north.

The mining district is nearly coextensive with the isolated group of peaks which have been called the Rico Mountains and which constitute an uplift distinct from the Mount Wilson group on the north, the San Juan Mountains on the northeast, and the La Plata Mountains on the south. On the west the Rico Mountains subside into the slightly inclined, dissected plateaus which stretch away into Utah.

HISTORY.

Records of the discovery and early development of the Rico ore bodies are fragmentary and often conflicting. The following data are drawn largely from an article entitled "The early trail blazers," which was published in the Rico News of June, 1892, and which was brought to my attention by Mr. G. W. Tower. The events recorded in this sketch, which bears evidence of careful preparation, have been verified as far as possible by comparison with other less extended references to the region, including Bancroft's History of Colorado, Frank Fossett's Colorado (the second edition of which was published at New York in 1880), and T. A. Rickard's Enterprise Mine.

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[1] The Enterprise mine, Rico, Colo.: Trans. Am. Inst. Mining Eng., Vol. XXVI, 1896, pp. 906–980. Also published, in part, under title Vein structure in the Enterprise mine: Proc. Colo. Sci. Soc., Vol. V, 1894–96, pp. 123–130.

[2] Geology of the Rico Mountains: Twenty-first Ann. Rept. U. S. Geol. Survey, 1899–1900, Pt. II, pp. 7–165.

[3] Cross and Spencer: loc. cit., Pl. XXII.

It is possible that some of the early Spanish explorers found their way up to the valley of the Dolores River, but the first party of white men known to have penetrated this region consisted of about 60 trappers from St. Louis, under the leadership of William G. Walton. This party set out from the trading post of Taos, N. Mex., and spent the summer of 1833 along the Dolores River and in camp near Trout Lake, about 13 miles northeast of the present site of Rico.

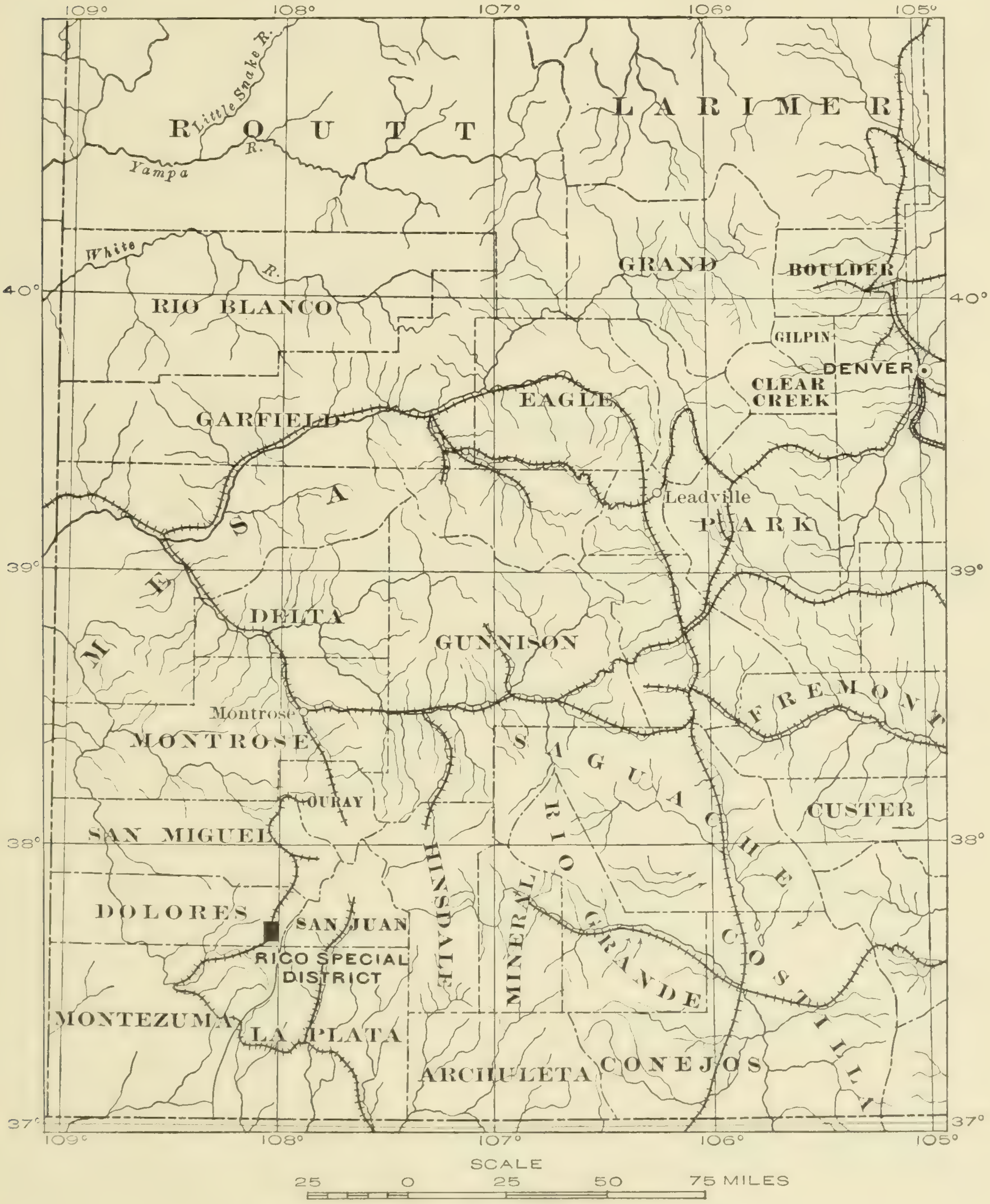

FIG. 39.—Index map showing position of Rico district.

In 1861 Lieutenant Howard and other members of John Baker's expedition into the San Juan region made their way over the mountains from the east and prospected the Dolores River, afterwards rejoining the main party at Bakers Park, where the town of Silverton now stands.

Five years later a party from Arizona, under Colonel Nash, following the Santa Fe and Salt Lake trail, reached the Big Bend of the Dolores (where the town of Dolores now stands), and explored the river to its source. Thence they crossed the divide to Trout Lake and proceeded down the San Miguel River.

In 1869 Sheldon Shafer and Joseph Fearheiler reached the site of Rico on their way from Santa Fe to Montana. They were well provided with tools and provisions and, struck by the indications of mineral wealth which the region afforded, decided to thoroughly prospect the district. They built a cabin on Silver Creek, near the spot where the South Park mine was afterwards opened, and located, in July, 1869, a claim which they called the Pioneer, a name that afterwards became the official designation of the mining district. It covered portions of what are now the Shamrock, Smuggler, and Riverside claims. They also made a location which they named the Nigger Baby, on account of the abundant black oxide of manganese found in the vein. Although this claim afterwards became part of the Phœnix mine, the name was perpetuated as Nigger Baby Hill. In the autumn of 1869 they built a more substantial cabin near where the Rico State Bank now stands, and worked on the Pioneer claim through the winter.

In 1870 R. C. Darling, engaged in surveying the boundaries of the Ute Indian Reservation, passed up the Dolores on his way to Mount Sneffels. He found Fearheiler and Shafer at work, located some claims near them, and proceeded on his way up stream. His name survives in Darling Ridge, one of the spurs of Expectation Mountain.

During the same year "Gus" Begole, John Echols, Dempsey Reese, and "Pony" Whittemore came into the district from New Mexico and discovered the Aztec and other lodes. On the approach of winter all of the prospectors relinquished their work and left the district. Fearheiler never returned, being killed by Indians on his way to Fort Defiance.

Apparently none of the adventurous prospectors came back to their claims in the following summer, but in 1872, Darling, who had succeeded in interesting some army officers and capitalists from Washington, D. C., in the resources of the region, led a large party into the Pioneer district from Santa Fe. They carried with them a few lengths of board from which they constructed molds for adobe bricks, and of these they erected a Mexican smelting furnace. Ore was extracted from what are now the Atlantic Cable, Aztec, Phœnix, and Yellow Jacket claims, and three small bars of bullion were produced in this furnace. The adobe, however, was not sufficiently refractory, and the furnace soon became useless. Discouraged by their failure and by the low grade of the bullion, the claims were abandoned on the approach of winter and the party returned to Santa Fe.

Two years later, members of the Hayden survey mapped the region and gave many of the existing names to the more prominent topographical features.

Prospecting was again resumed in the Pioneer district in 1877, and in 1878 became active through the energy of John Glasgow, "Sandy" Campbell, David Swickhimer, and others. The Atlantic Cable, Blackhawk, Hope, Cross, Grand View, Major, Phœnix, Yellow Jacket, Pelican, Aztec, and Columbia claims were all located in 1878, but, as usual, work was abandoned when the winter snows whitened the surrounding peaks.

In the spring of 1879, rich oxidized silver ore was discovered on Nigger Baby Hill and a rush to the district from the neighboring camps followed. Several claims on Nigger Baby Hill were sold to the Grand View Mining Company, in which Senator Jones and John W. Mackay, well known for their operations on the Comstock, were prominent stockholders. Ore was also found in the Chestnut vein, on Newman Hill, and a small shipment was made to Swansea.

The beginnings of a settlement sprang up. The town site was surveyed and divided into lots, and E. A. Robinson became justice of the peace. The first newspaper, the Dolores News, appeared on August 21, the first seven numbers being printed in Silverton. A post-office was opened and the name Rico was given to the growing town.

The Grand View smelter was begun in 1880, the machinery coming from the railway terminus at Alamosa by wagons to Mancos, and thence over the now abandoned road which reached the Dolores River by the dreaded Bear Creek Hill, 12 miles south of Rico. The freight from Alamosa was about $300 per ton. Late in the autumn the smelter began producing bullion. This same year saw the discovery of the Johnny Bull ore body.

The year 1881 is notable for a punitive expedition against a party of Utes, who were overtaken near the La Sal Mountains and defeated, with considerable loss of life on both sides.

The following spring the Rico Mining and Smelting Company began the erection of a second smelter in the southern end of town, and the Newman group of mines was sold to the Marrs Consolidated Mining Company for $175,000.

In 1883 the finding of ore in the South Park mine, on Silver Creek, led to active prospecting along this stream.

In 1884 the Rico smelter was purchased and repaired by the Pasadena Company, and was operated as a custom plant for nearly two years.

As early as 1881 David Swickhimer, Patrick Cain, and John Gault began a shaft on the Enterprise claim on Newman Hill, but subsequently sold their property for a few hundred dollars' worth of lumber. But the success of Larned and Hackett in following the veins in the Chestnut and Swansea claims led Swickhimer to repurchase a controlling interest in the Enterprise, and in October, 1887, he struck ore at a depth of 262 feet. This was the first discovery of the so-called "contact" or blanket ore, and the shaft had fortunately cut the edge of the largest and richest ore body ever found on Newman Hill.

The result of Swickhimer's discovery was to infuse new life into the district. Large bodies of ore were found in the Blackhawk, Logan, and Rico-Aspen mines, and the future of Rico looked brighter than ever before.

The Enterprise group was sold in 1890 to a Pittsburg company, and the same year saw the advent of the Rio Grande Southern Railroad. Litigation sprang up between the Enterprise and Rico-Aspen companies, but production went on, and when the suit was finally won by the Enterprise the ore in the disputed territory had been extracted, largely by the Rico-Aspen Company.

Since 1895 the output of the Pioneer district has decreased. The large bodies of rich "contact" ore have been mined out and many of the veins have been worked down to a depth at which the ore no longer pays for shipment. Masses of ore often proved to be curiously limited, owing to various conditions that are characteristic of the region, and that will be described in the following pages. The declining price of silver has had a depressing effect on this, as on other districts, where this metal forms a large part of the output. But nearly all the important ore bodies formerly exploited were sufficiently rich to be workable to-day had they not been exhausted.

In the year 1900 the only ore being shipped from the district was an occasional carload taken out by leasers working small areas of unexplored ground in the larger mines. Whether the present inactivity is final or not is a question that can not be decided offhand. Prosperity and depression, following each other in rhythmic procession, are the lot of many mining districts, and it is often difficult to distinguish a state of quiescence from one of extinction.

Whatever the economic future of the Pioneer district may be, the modes of occurrence of its ores present many problems of unusual and living interest. After a consideration of these, the question of a possible revival of mining activity may be more intelligently answered.

PRODUCTION.

The total production of the Pioneer mining district can be only roughly estimated. According to the reports of the Director of the Mint, the output from 1879 to the end of 1900 has been about 73,000 ounces of gold and 9,000,000 ounces of silver. It is estimated that the value of the entire output, including the base metals, lies somewhere between $8,000,000 and $10,000,000. By far the greater part of this has been silver.

CLIMATE AND VEGETATION.

The climate of Rico can be described only in general terms, as there are no meteorological data available. The winters are less severe than at Silverton, which lies in the heart of the neighboring San Juan Mountains, but are nevertheless characterized by heavy snows, which may begin in September or October. As most of the Rico mines are below timber line, the danger from snowslides is less than in the higher and more rugged regions of the San Juan. The summers, as might be expected at altitudes ranging from about 8,500 to 12,600 feet, are pleasantly cool, and in normal years thunder showers are of frequent occurrence in July and August.

The mountain slopes are well covered with aspens, spruce, and balsam fir up to a timber line varying from 11,500 to 12,000 feet in altitude. The aspens are particularly abundant on the lower slopes, often forming a luxuriant second growth upon the site of earlier aspen woods which have been cut away. Both spruces and aspens are used for mine timbering, the aspens being valuable on account of their proximity to most of the mines and the rapidity with which new trees spring up to take the place of those felled.

Among the smaller shrubs, the wild raspberry flourishes abundantly and becomes laden with fruit in August or September, while through early summer the usual wild flowers common in Colorado at these altitudes bloom in gay profusion.

TOPOGRAPHY.

As fully described by Cross and Spencer in their paper already referred to, the compact cluster of peaks known as the Rico Mountains is the remains of a much dissected structural dome rising above the Dolores Plateau. To the west this plateau, which near the Rico Mountains has an elevation of about 9,400 feet, stretches away into Utah. On the north, east, and south the original horizontal plateau structure has been somewhat modified by the elevation of the Wilson, San Juan, and La Plata mountain groups, and of the Rico Mountains themselves. The Dolores River crosses the Rico dome from north to south, and through erosion by this stream and its tributaries the Rico dome, traversed by numerous fault fissures, has been carved into peaks and canyons. The highest of these peaks is Blackhawk, with an elevation of 12,677 feet. The lowest point in the district covered by the map is about 8,600 feet, near the mouth of Spruce Gulch.

While the topography is thoroughly mountainous it is by no means of so rugged a character as that of the San Juan Mountains. The comparative smoothness of the wooded slopes about Rico is largely due to the remarkable extent to which landslides and accumulations of surface wash have buried and cloaked the lower slopes of the mountains. Inspection of the geological map (Pl. XLI) shows how almost the entire eastern slope of Expectation Mountain, the western slopes of C. H. C. and Newman hills, and many smaller areas are covered by surficial material.

GENERAL GEOLOGY.

The geological structure and history of the Rico Mountains have been admirably treated by Cross and Spencer in the report already cited. The reader is referred to that work, and particularly to the terse outline by Mr. Cross which forms the first chapter, for an account of the general geological features, knowledge of which is presupposed in the discussion of the ore deposits. But in order that the present report may not be wholly unintelligible in the absence of its companion paper, the following outline sketch has been prepared from the latter.

The accompanying geological map (Pl. XLI) includes but the central portion of the Rico "special area," of which a complete geological map may be found in Cross and Spencer's paper.[1]

The Rico Mountains are structurally determined by a local, dome-like uplift of originally nearly horizontal strata.[2] This uplift was due in minor part to the intrusion of masses of molten igneous rock, chiefly monzonite and monzonite-porphyry, in the form of sills, stocks, and dikes. But the greater portion of the elevation was effected by later upthrust and faulting. From north to south the dome is about 12 miles in diameter, and from east to west about 15 miles. The original vertical extent of the uplift is estimated at about 4,500 feet. This structural dome is now traversed from north to south by the Dolores River, and has been deeply eroded, particularly in its central portion, resulting in the present topography.

The rocks involved in this uplift range from Algonkian to Juratrias, the older being exposed in the central part of the area and the younger on its periphery. The Algonkian rocks consist of quartzites and schists, exposed just north of Rico and in the canyon of Silver Creek. They appear as fault blocks, in the heart of the dome, thrust

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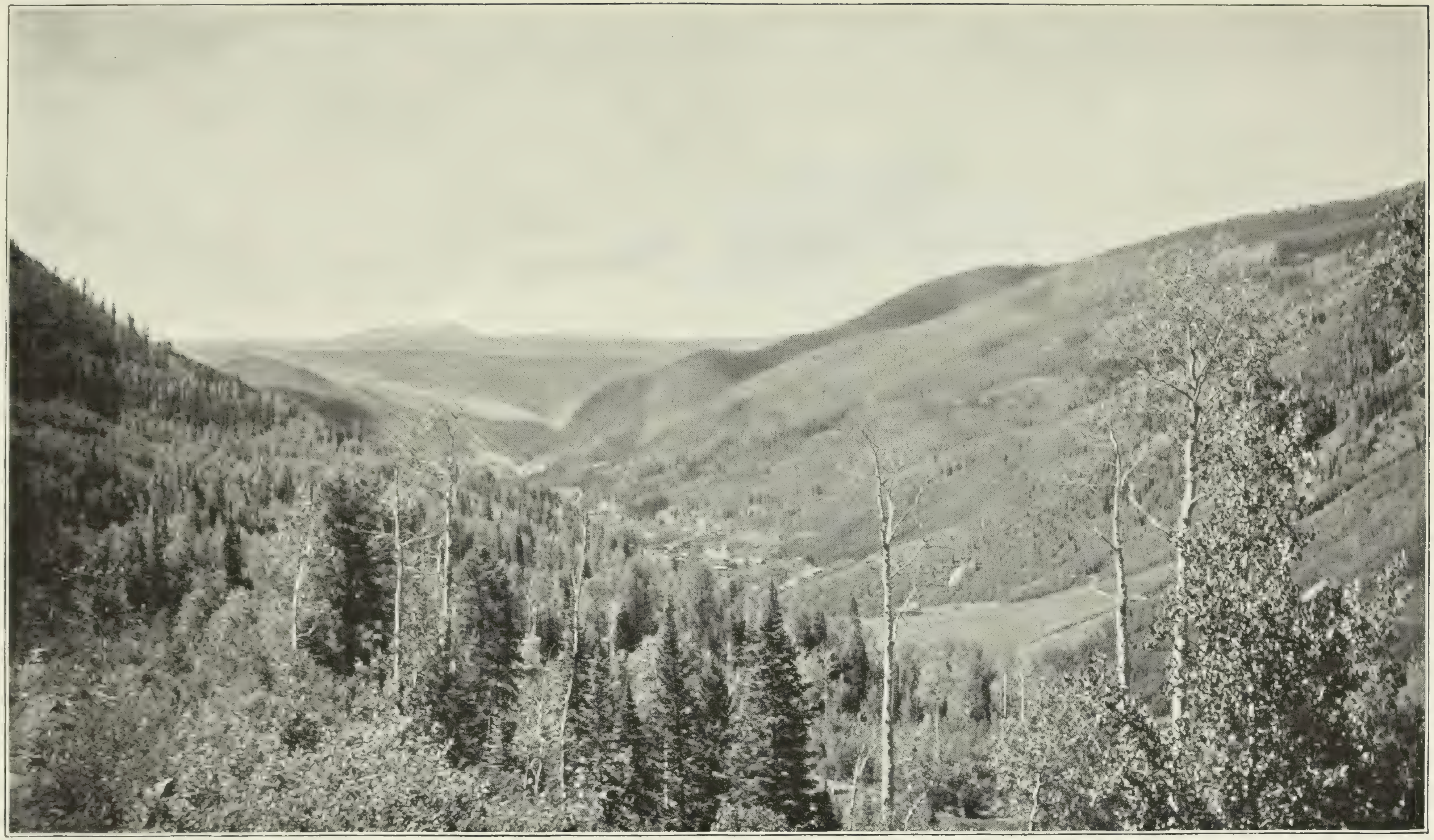
[1] Loc. cit., Pl. XXII.

[2] Ibid, Pl. VIII.



LOOKING SOUTH FROM C. H. C. HILL DOWN THE VALLEY OF THE DOLORES RIVER.

The town of Rico, in the middleground, lies in the center of the structural dome of the Rico Mountains. The isolated group of the La Plata Mountains appears on the distant sky line.

up from below into the later beds. Rocks of Devonian age are represented by massive limestone (the Ouray limestone) and an underlying quartzite. The former is exposed at the north end of the town of Rico and is much metamorphosed. The quartzite is seen in but few outcrops, and its base is nowhere revealed.

Above the Ouray limestone lies a thick series of sandstones, shales, and limestones, which pass up without any apparent unconformity into the Juratrias. This series is not readily separable into natural divisions on lithological grounds alone, but by the aid of certain fossiliferous beds Cross and Spencer have succeeded in dividing it into formations referable to different geological periods.

The beds immediately above the Devonian are Upper Carboniferous, and have been named the Hermosa formation. This formation has been further subdivided into a lower member of shales, sandstones, and subordinate limestones, a middle member, prevailingly limestones, and an upper member of shales and limestones. The middle member of the Hermosa is conspicuously represented in the cliffs of gray limestone which rise behind Newman Hill. The lower and middle members are mapped as a unit and indicated by a single color. The entire thickness of the Hermosa is about 1,800 feet.

Above the Hermosa lies the Rico formation, belonging to the Permo-Carboniferous, and consisting of coarse arkose sandstones, shales, and sandy, impure limestones. The prevailing color of these beds is dark maroon or chocolate, while the dominant tint of the Hermosa is gray. The base of the Rico lies a few feet above a sandy and very fossiliferous limestone containing *Fusulina cylindrica*, which is almost at the top of the Hermosa. The formation has a total thickness of about 300 feet.

Succeeding the Rico is the Dolores formation, included in the Juratrias, but probably corresponding to the Trias. It consists of sandstones, conglomerates, and sandy shales and limestones, prevailingly brick-red in color, and aggregating 1,600 feet in thickness. These are in part the familiar "Red Beds" of the Rocky Mountain region.

Overlying the Dolores is the La Plata formation, presumably Jurassic, consisting of two thick beds of light-colored sandstone separated by a thin bed of limestone. Its aggregate thickness in this region varies from 250 to 500 feet.

The La Plata is in turn succeeded by the McElmo beds, composed of variegated reddish and greenish shales and sandstones. The McElmo formation is regarded as Jurassic and is the youngest stratigraphic unit involved in the structure of the Rico dome, which is now preserved within the area described.

The last two formations occur only near the edges of the Rico area and contain no important ore deposits. All of the beds above the Devonian conform generally to the domical structure, dipping away on all sides from the geographical center of the uplift, which corresponds approximately to the town of Rico.

The foregoing sedimentary formations were intruded at an early stage of the uplift by numerous igneous masses in the forms of stocks, sills, and dikes. The intrusive magma solidified as monzonite or monzonite-porphyry. The occurrence of the stocks is well illustrated by the eruptive masses of Darling Ridge and Calico Peak. The sheets, or sills, and dikes are most abundant in the rocks of the Dolores formation, particularly near the head of Horse Creek.

After the igneous rocks had solidified the dome was further deformed by extensive faulting, the displacement in some cases exceeding 1,000 feet. The more important faults are indicated upon the geological map and are fully described in Cross and Spencer's report.

The later geological history of the region has been one of erosion and landsliding on an extensive scale, both of which closely connected processes have had an important influence upon mining developments. Although the landslides have obscured the relations of the ore bodies, erosion, on the other hand, by carving out the present mountains and canyons, has revealed the existence of the ores and rendered possible their exploitation.

PRELIMINARY OUTLINE OF THE ORE DEPOSITS.

The ores of the Rico district show unusual variety in their occurrence as regards both form and genesis. To classify them strictly and consistently, in accordance with either shape or origin, would be difficult and for ordinary purposes confusing. The units of such classification would, in many cases, be not ore bodies, but parts of ore bodies. It is proposed in this report to treat the deposits under four general heads, namely: (1) lodes, (2) blankets (*Lagergänge*, or bed veins, of von Cotta, in part), (3) replacements in limestone, and (4) stocks. This is confessedly and obviously a rough grouping for convenience and clearness of treatment, and is not intended as a scientific classification.

Under the first head will be described simple or complex fissure veins, usually nearly vertical, which when they occur in sedimentary formations cut across the planes of bedding. They are fractures or fissures in the rocks, which have been afterwards filled with ore or valueless vein matter.

Under the second head will be treated various deposits usually more nearly horizontal than vertical, and lying parallel to the planes of bedding or to the surfaces of intruded sheets of igneous rock. These are the deposits locally known as "contacts." This term, used in a sense that has no necessary connection with its true geological meaning, has unfortunately found its way into literature,[1] and has been so

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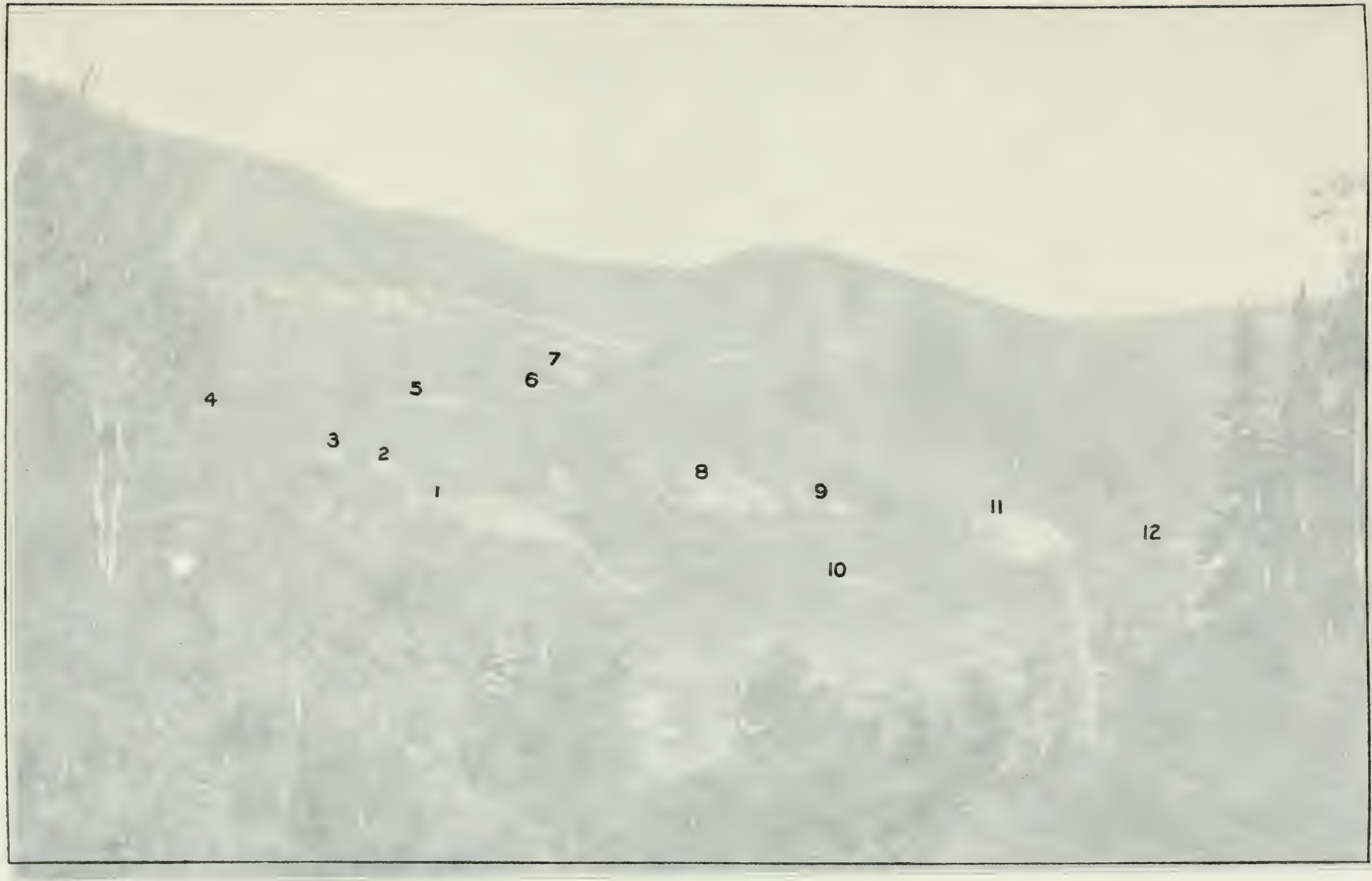
[1] Farish, loc. cit., uses the word "contact" in quotation marks, but Rickard, loc. cit., provides no such safeguard against confusion.



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1. Enterprise mine, group tunnel.
2. Silver Age tunnel.
3. Wakeman and Golden Age tunnel.
4. Isabella shaft.
5. Enterprise shaft.
6. Jumbo shaft.
7. Vestal shaft.
8. Newman mines.
9. Stephens tunnel.
10. Lexington tunnel.
11. Rico-Aspen mine, Syndicate tunnel.
12. Stephanite tunnel.

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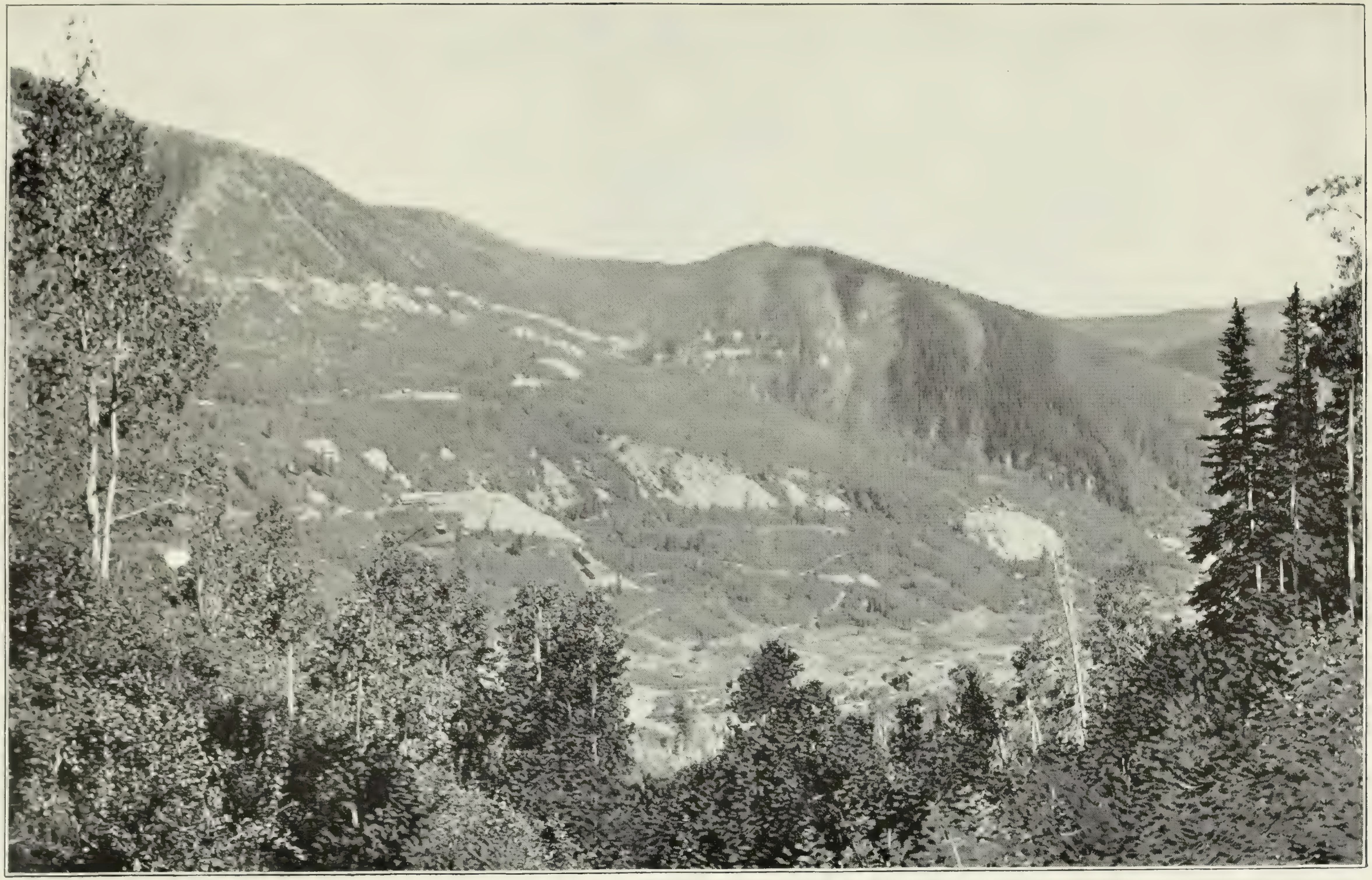

NEWMAN HILL, FROM THE NORTHWEST.

universally adopted by the miners that it is difficult to altogether avoid its use. Wherever employed, however, the word will be placed in quotation marks, indicating its true standing as miners' vernacular.

Under the third head will be considered those deposits, often irregular in form, which have resulted from the metasomatic replacement of limestone by ore.

Lastly, under the fourth head, will be noticed a few small ore bodies often referred to as "chimneys," of which the Johnny Bull is the principal example in this region.

It will be shown later on that no sharp distinction exists between these various deposits. Lodes of flat dip may pass into bedding faults along weak strata, producing breccias which, when mineralized, are classed as blankets. The mineralization of such a breccia, particularly if the material be calcareous shale, is likely to be largely by metasomatic replacement, producing a deposit closely akin to those resulting from the simple replacement of limestone. Moreover, the ore bodies grouped under the second and third heads are always intimately connected with fissures or lodes which may or may not be themselves productive.

The greater part of the product of the district has come from the blankets. Some of the lodes have proved rich, but their value has invariably fallen below the limit of profitable working at a remarkably shallow depth, which generally bears a constant relation to some overlying blanket with which the lode or lodes connect. Some important bodies of ore have also been formed by direct replacement of limestone.

The bulk of the ore has been found in the Carboniferous sedimentary series, particularly that portion of it known as the Hermosa formation. This is nearly equivalent to saying that most of the ore has come from the central portion of the district, in the heart of the domical uplift of the Rico Mountains.

The ores consist primarily of galena, often highly argentiferous and associated with rich silver-bearing minerals. In many deposits more or less complete oxidation of the primary ores has taken place, resulting in pulverulent earthy ores, often very rich in silver.

DISTRIBUTION OF THE ORES.

In all probability more than half of the ore produced in the Rico district has come from Newman Hill. This name is applied to the slopes immediately south and east of Rico, constituting the western flank of Dolores Mountain. Newman Hill may be considered as bounded on the north by Silver Creek, on the west by the Dolores River, on the south by Deadwood Gulch, and on the east by the cliffs formed by the massive bed of limestone characteristic of the medial division of the Hermosa. On this slope, which is deeply covered with surface wash, are the Enterprise, Rico-Aspen, Newman, Union-Carbonate, and other mines, in which the ore occurred partly in lodes and partly in blankets. Of the latter the principal one is locally known as the Newman Hill, or Enterprise, "contact."

Also on the east side of the Dolores River, but north of Silver Creek, is Nigger Baby Hill, a spur of Telescope Mountain. This hill has been productive since 1879. The ore occurs in oxidized form in lodes, which in their upper portions possess so flat a dip as to constitute essentially blanket deposits.

C. H. C. Hill lies immediately north of Nigger Baby Hill. It is a landslide area, honeycombed with workings, from which much ore has been taken. The ore, largely oxidized, occurs in blankets, the continuity of which has been greatly broken by landslide movements.

From the three hills mentioned has come the greater part of the Rico ore. There are, however, several important outlying deposits. The most prominent of these is in the Blackhawk mine, between Silver Creek and Allyn Gulch, where the ore occurs oxidized in a lode and as sulphide replacement deposits in massive limestone. Another example is the Puzzle mine, on Horse Creek, about three-quarters of a mile from its mouth, where the ore also occurred replacing limestone. The Johnny Bull mine, on Johnny Bull Mountain, near the head of Horse Creek, has also produced some ore.

The entire basin of Horse Creek and the eastern slope of Expectation Mountain are dotted with prospects, many of which have produced small quantities of ore, but nearly all are now abandoned.

By reference to the geological map (Pl. XLI) the preponderance of the important ore bodies occurring in the Hermosa, particularly the Lower and Middle Hermosa, will be evident. Near the periphery of the dome, where the Juratrias sediments now constitute the surface, no large ore bodies have been found. The Johnny Bull, it is true, occurs in these rocks, but the ore body, although at one time giving rise to considerable excitement, proved to be little more than a pocket.

MINERALOGY OF THE ORES.

The ores of the Rico district present few noteworthy or peculiar mineralogical features, and need receive but brief treatment under this head. The bulk of them may be roughly divided into (1) pyritic ores, usually of very low grade, and (2) argentiferous galena ores, sometimes containing rich silver minerals. The former constitute the characteristic vein filling of most of the lodes, and also occur in many of the blankets and other deposits. The latter form the workable ore bodies, deposited under various specially favorable circumstances of concentration. The two kinds of ore are not capable of sharp mineralogical or commercial distinction, and are not necessarily of different age.

The minerals occurring as a direct result of the general processes of mineralization may be classed as ore minerals and gangue minerals. Among the former are included all of the so-called "metallic minerals," whether or no they actually constitute ore in the commercial sense. Under the latter are embraced those nonmetallic minerals, such as quartz, which commonly serve as matrix for the valuable ore constituents.

ORE MINERALS.

Pyrite is by far the most abundant ore mineral in the district. Associated with quartz and small amounts of chalcopyrite, sphalerite, and galena, it constitutes the practically worthless filling of most of the lodes. It is found in large blanket-like masses, free from gangue, in C. H. C. Hill. In similar masses, but usually in more solid condition, it is abundant as a replacement of limestone. This is the mode of its occurrence in the Blackhawk mine, where it is frequently associated with fluorite, and grades by increase of chalcopyrite and galena into workable ore. Although commonly containing small quantities of silver and gold, the pyrite has hitherto proved too low in grade for successful treatment. Rickard[1] records that the pyrite from the northwesterly lodes in the Enterprise mine usually afforded on assay from 4 to 8 ounces of silver and traces of gold. In the Gold Anchor prospect in Bull Basin, a large body of pyrite was found which is said to have indicated, in single assays, as much as 90 ounces of gold per ton, but which as a whole did not pay the cost of extraction.

Galena, a very important ore mineral, occurs abundantly in the Enterprise blanket and in most of the bodies of unoxidized ore that have been worked in the district. It is always argentiferous, but apparently does not constitute rich ore unless accompanied by argentite, tetrahedrite (freibergite?), proustite, or polybasite, as is the case in the Newman Hill mines. On the other hand, it nowhere occurs in sufficiently large masses to be workable for its lead alone. It presents no unusual peculiarities in this region, and is, as elsewhere, nearly always accompanied by sphalerite.

Sphalerite, or zinc blende, is an abundant constituent of the rich ores of Newman Hill, which sometimes contain over 15 per cent of zinc. Its common associates in these ores are galena, chalcopyrite, rhodochrosite, and quartz, and it occurs both in the northeasterly lodes and in the blanket. It is also found in massive granular form, associated with a little chalcopyrite, galena, and fluorite, in the Blackhawk mine, where it makes up a considerable part of the large replacement bodies in limestone. In the Atlantic Cable claim it occurs in coarsely crystalline nodular masses, associated with chlorite, specularite, chalcopyrite, and galena, in limestone. This sphalerite is dark brown, while that in the Newman Hill veins is usually rosin colored. It is also abundant in the Sambo mine, and in the Bancroft and Lily D. prospects, associated with galena. The occurrence of sphalerite has hitherto been purely an objectionable feature in the ores, owing to the penalty attached by the smelters to ores containing over 10 per cent of zinc. But in 1900 experiments were being made to determine the feasibility of working some of the sphaleritic ores for zinc alone, and in 1901 zinc ore was being extracted in commercial quantities from the Atlantic Cable and Bancroft claims.

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[1] Loc. cit., p. 940.

Chalcopyrite, or copper pyrite, is not very abundant in the Rico district, although nearly always present with galena and sphalerite in the workable ores. Associated with pyrite, fluorite, and some finely granular galena and sphalerite, it formed some of the best ore in the Blackhawk replacement bodies, where it often occurred in fine concentric or irregularly curved, narrow bands. It is present in small quantity in the blanket and lode ores of Newman Hill, in the Silver Swan, Aztec, and Atlantic Cable prospects, and in many other lodes and blankets throughout the district.

Tetrahedrite, or gray copper ore, occurs in the rich blanket ores of the Enterprise and Rico-Aspen mines and in some of the northeasterly lodes. It is a valuable constituent on account of its argentiferous character. It is here associated with sphalerite, polybasite, galena, rhodochrosite, and quartz. It also occurs in these mines in ore replacing gypsum, the gangue in such cases being partly the transparent crystalline form of gypsum known as selenite. Small amounts of tetrahedrite are found replacing sandstone in the Gold Anchor prospect in Bull Basin. It is probably present also in the Aztec lode, with chalcopyrite, and may have formed part of the Johnny Bull ore. A small pocket of tetrahedrite was extracted from the Iron lode, but the mineral apparently does not occur in the replacement deposits of this mine. A little occurs also, with quartz, in the Eureka, a prospect near the head of Iron Draw. It is nowhere abundant, and is generally indicative of high-grade ore, although the latter is not necessarily present in large amount.

Specularite, the crystalline variety of hematite, occurs abundantly in several mines and prospects in the metamorphosed Devonian beds near Rico. Among these may be named the Iron Dollar, Eighty-Eight, Atlantic Cable, Shamrock, and Smuggler. It is closely associated with chlorite, epidote, garnet, and wollastonite (and perhaps vesuvianite), as well as galena, sphalerite, and chalcopyrite, and its formation was evidently connected with the metamorphism of the Devonian limestone. It is of no value as an ore in this region, but has been sometimes mistaken for sphalerite.

Magnetite has been mined in small amounts for fluxing purposes from the Magnet prospect on the north side of Darling Ridge, and from the Eagle prospect near the head of Sulphur Creek. It occurs massive, with a little chalcopyrite, replacing limestone. It may contain half an ounce of silver and $2 in gold per ton. Some magnetite occurs in the Atlantic Cable claim, with specularite.

Argentite, *proustite*, *polybasite*, and perhaps *stephanite*, occur in the rich blanket and lode ores of Newman Hill. They were evidently among the last ore minerals to form, and to them was mainly due the richness of these deposits. They are almost invariably found in vugs in the more solid ore, and when present in the lodes occur along the medial plane of the vein in the spaces left by the comb structure of the quartz and other minerals. Argentite is found in black, rounded masses, suggestive of particles of shoemaker's wax, which have softened and fitted themselves to the interstices between the earlier crystals. Polybasite and proustite also occur in vugs, but in implanted crystals of the forms characterizing these minerals. Stephanite was not identified at the time of visit, but its occurrence has been reported by Farish,[1] who also mentions pyrargyrite. These rich silver-bearing minerals were not seen elsewhere in the district in 1900; but argentite is said to have occurred in the Puzzle mine, in a quartzose gangue, replacing limestone.

Native silver is reported from the Enterprise and Puzzle mines, but none was seen in 1900. It was probably a product of oxidation.

Free gold is rarely detected in the Rico ore deposits. Some is said to have been found associated with sphalerite and chalcopyrite in the Enterprise mine, and some embedded in rhodochrosite in the Eureka vein of the same mine. A little free gold has also been found in prospects near Calico Peak, but none was seen in place. The ore of the Johnny Bull mine contained considerable gold, with tellurium and traces of bismuth, but it is not known whether any of the gold occurred native. Gold, associated with a little molybdenum, occurred in the Uncle Remus mine, but whether free or not can not now be ascertained.

Native copper was noted only in the California prospect near the head of Iron Draw, as small crystalline sheets or skins in the country rock.

GANGUE MINERALS.

Quartz is by far the most abundant gangue mineral in the region. It is nearly always associated with pyrite and constitutes the common filling of the lode fissures. Although usually present in the workable ores, it is there associated with other gangue minerals. The lode quartz shows no special features peculiar to this region and demands no detailed description. In the form of jasperoid[2] (a cryptocrystalline aggregate commonly associated with replacement deposits) quartz occurs in the Blackhawk mine, in the Atlantic Cable claim, and in the blanket of the Sambo mine. In the Blackhawk mine, also, are found spongy, cavernous masses of rusty quartz, apparently due to the removal of limestone, by solution, from a network of quartz stringers (Pl. XXVIII, *A*). Quartz is abundant in some of the blanket breccias as a replacement of the brecciated material. In the case of the nearly black Hermosa shales, many of the fragments are still recognizable as dark patches in the white quartz, although the microscope shows that they have been altered to cryptocrystalline quartzose aggregates. In the main blanket of the Union-Carbonate mine, fragments of monzonite-porphyry have been more or less completely transformed into very spongy masses of white quartz, sometimes containing pyrite. A somewhat similar silicification of porphyry has taken place alongside the lode fissures of the Mohawk and Marriage Stake prospects, in Horse Gulch. In these cases, however, the resulting siliceous skeleton still preserves in a measure the original porphyritic appearance of the rock.

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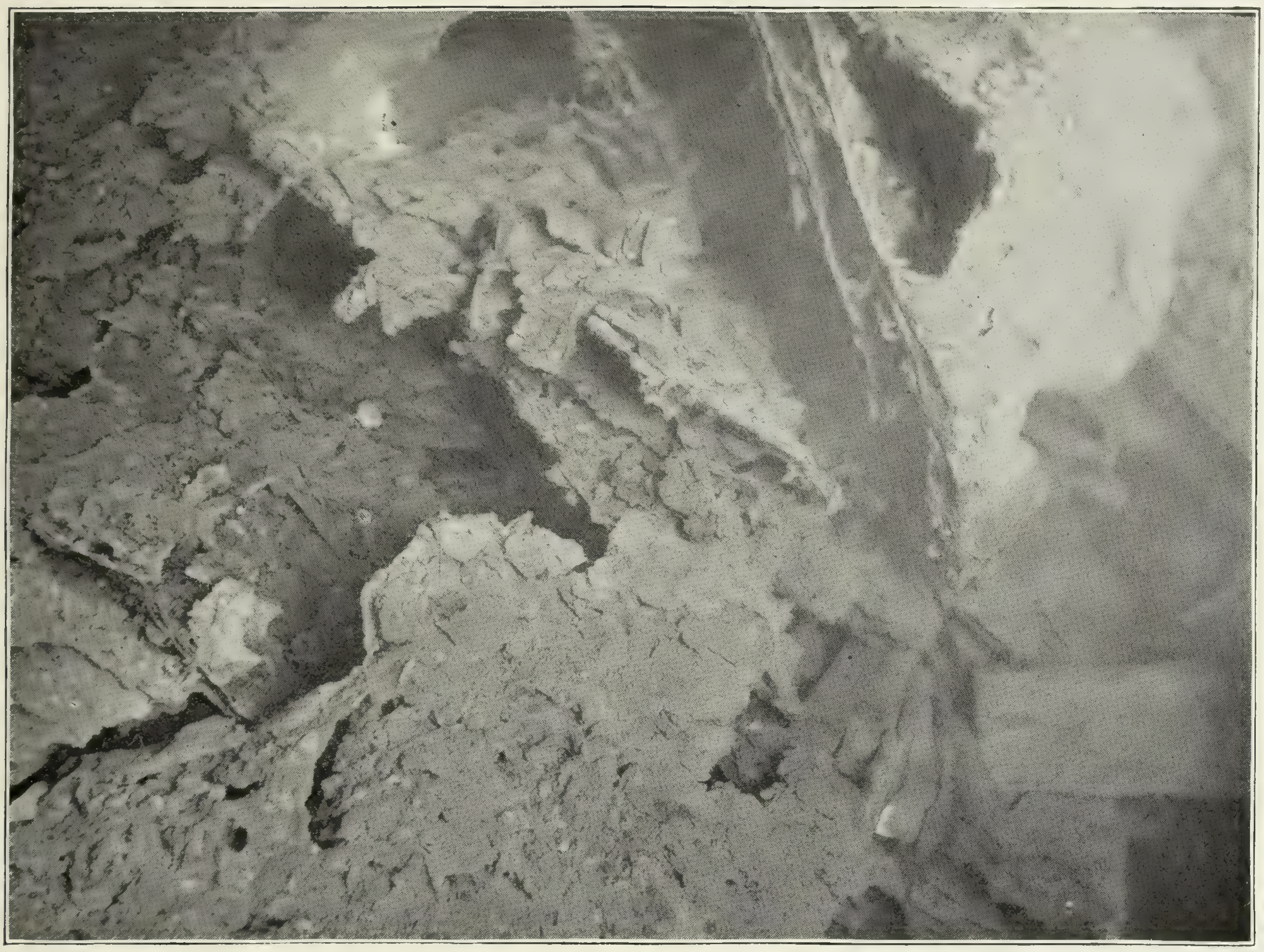
[1] Loc. cit., p. 161.

[2] See J. E. Spurr, Mon. U. S. Geol. Survey Vol. XXXI, 1898, p. 219.

Rhodochrosite, the carbonate of manganese, is present in the rich upper portions of the northeasterly lodes of Newman Hill and in the Enterprise blanket. Its delicate pink color makes it easily recognizable, and it is important in these mines as a rough indication of good ore. It occurs massive, often irregularly but beautifully banded with the quartz and ore of the lodes. It does not, as far as known, occur in this region in the large well-formed rhombohedral crystals which characterize it in some other localities. A little residual rhodochrosite was noted in the oxidized Little Maggie vein, at the Blackhawk mine, but it is not generally abundant outside of Newman Hill. Some of the "spar" veins in other portions of the region have a slight pinkish tint, however, and decompose in part to black oxide of manganese, showing either that some of this mineral is present, or that the "spar" is manganiferous.

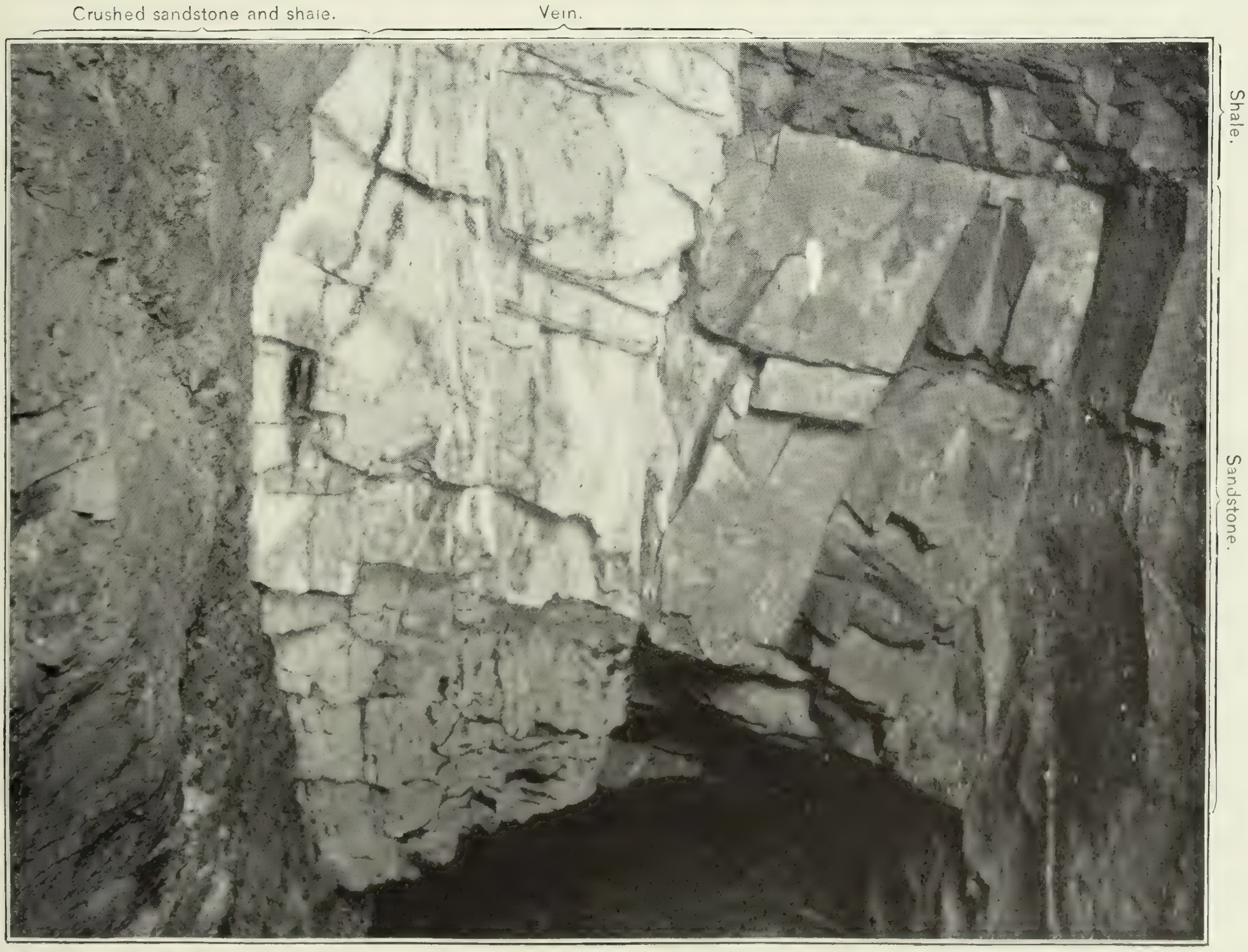
Calcite, or the common "spar" of the miners, is abundant in the veins of Nigger Baby Hill, where it takes the usual place of quartz as the principal gangue mineral. It is generally finely crystalline, more or less impure, and often resembles ordinary limestone. It is always manganiferous, and readily undergoes decomposition, whereby the calcium carbonate is largely removed and a soft black mass of oxidized manganiferous ore left behind. Calcite is naturally often present as gangue in the replacements of limestone by ore.

Fluorite, or fluorspar, is not of widespread occurrence in the Rico ore deposits, but is abundant in the displacement ore bodies of the Blackhawk mine and in the Fortune and Duncan prospect north of Silver Creek. In the Blackhawk it forms the gangue of pyrite, chalcopyrite, sphalerite, and galena in the large pay shoot outcropping at the surface near the bunk house. It is pale lilac, pink, or color-



A. CAVERNOUS, RUSTY QUARTZ, AS SEEN ON THE M LEVEL OF THE BLACKHAWK MINE.

Photograph by G. W. Tower.



B JUMBO NO. 3 VEIN, NEAR THE NORTH BREAST OF THE 150-FOOT LEVEL, ENTERPRISE MINE.

Photograph by G. W. Tower.

less, and easily recognized by its hardness and cleavage. In the Fortune and Duncan it constitutes the gangue of a low-grade pyritic ore occupying a breccia zone between quartzite and limestone. It is nearly colorless, with slight pinkish and greenish tints, and forms with pyrite and chalcopyrite a friable crystalline aggregate. A small quantity of fluorite also occurs in the Hibernia tunnel.

Gypsum occurs as a gangue mineral, so far as observed, only in those ores which have replaced massive gypsum in Newman Hill. A portion of the gypsum has in such cases recrystallized as transparent plates of selenite.

Barite is not known in this region as the gangue of any workable ore body. It occurs, however, on a claim adjoining the Aztec mine, in a vein supposed to be the same as that worked in the latter mine.

Chlorite occurs abundantly as a gangue for sphalerite, chalcopyrite and specularite, in the Atlantic Cable and other prospects in the Devonian limestone. It is cryptocrystalline and massive.

Kaolinite and *sericite* are not abundant in this region, and can scarcely be considered as gangue minerals. Some of the former mineral, however, occurs associated with the ore in the Johnny Bull mine, while sericite is found in connection with the C. H. C. Hill blanket.

PARAGENESIS.

By *paragenesis* is here meant the association of the various ore and gangue minerals, with special reference to the mode and order of their formation.

Although these minerals, as indicated in the preceding section, are commonly found in more or less characteristic association, no constant and regular order of deposition has been discovered. Careful study of the banded veins of Newman Hill has failed to show that this banding can be explained by any simple depositional sequence of the component minerals. Each mineral has evidently been developed at many different times during the whole period of mineralization. The only generalizations which it appears safe to make are that in Newman Hill the rich silver ores, proustite, argentite, and polybasite, were the last ore minerals to form in the northeasterly lodes and in the Enterprise blanket, and that there was deposition of practically barren quartz and a little pyrite, which was also subsequent to the formation of the galena, sphalerite, and rhodochrosite. Whether this barren veining preceded, followed, or coincided with the deposition of the rich silver minerals, is not known. It is supposed to have followed it.

PRODUCTS OF OXIDATION OR WEATHERING.

The access of surface waters to the upper portions of many of the lodes and to some of the blankets and replacement ore bodies has resulted in a variety of products, many of them earthy and of obscure mineralogical character. The rather thorough oxidation of the shattered pyritic blankets of C. H. C. Hill has given rise to great masses of limonitic iron ore, sometimes containing gold and silver, but usually of no value. Associated with this are earthy lead sulphate, pulverulent hydrous silica, jarosite (hydrous sulphate of iron and potash), sericite, halloysite, gypsum (derived from limestone by sulphate solutions from oxidizing pyrite), silver in unknown combination, and probably many other minerals. In Nigger Baby Hill the decay of the calcitic veins to a depth of some 200 feet has resulted in soft, black, earthy ores consisting largely of hydrous oxides of manganese and iron, obscure hydrous compounds of alumina, carbonates of copper in small amounts, and silver, lead, and zinc in unknown conditions, probably in part as carbonates. Similar products have resulted from the alteration of a bed of impure limestone in the Forest-Payroll mine. In the Puzzle mine the argentite is stated by Purington[1] to have been partly altered to native silver and to embolite, the chlorbromide of silver; and on the M. A. C. claim, adjoining the Puzzle, in a shaft now inaccessible, was found a soft mass of pale-blue allophane (hydrous silicate of alumina) and kaolinite in a cavity dissolved in the limestone.

Although not strictly a product of oxidation and weathering, it may be well to mention in this place the pulverulent gray mixture of dolomite and celestite which has remained as a residue after the solution of the gypsum of Newman Hill.

OCCURRENCE OF THE ORES.

DEFINITIONS.

While it is undesirable in a report of this character to enter at length into the complex subject of the classification and nomenclature of ore bodies, it is essential to clearness of presentation that the meanings of such terms as are used in the description of the Rico ore deposits should be clearly understood. The following definitions are intended to make plain the terminology adopted in this paper, and need have no currency outside of its pages.

Fissure vein is used as von Cotta defined it—the filling of a fissure. *Lode* is applied as a more comprehensive term, and may mean either a simple fissure vein or a complex assemblage of closely spaced veins or stringers, sometimes including a certain proportion of mineralized country rock occurring alongside of and within the fissure zone. A lode is roughly tabular in form and when occurring in sedimentary rocks cuts across the beds at an appreciable angle. It is usually more nearly vertical than horizontal. That portion of a vein or lode which consists of workable ore is termed a *pay shoot*.

The word *blanket* is used to designate a zone or lens, composed of mechanically or chemically disintegrated material, lying parallel to the bedding of the sedimentary series within which it is inclosed. Such a mass is always referred to as a "contact" by the miners of Rico. In contradistinction to a lode a blanket is usually more nearly horizontal than vertical. The material of a blanket is normally soft as compared with the rocks which immediately overlie or underlie it. In most cases its unconsolidated character is due to the brecciation or chemical alteration of a bed which either was originally intrinsically weak or has been placed in such circumstances as to become disintegrated. Various blankets will be described, due to different combinations of causes, from simple brecciation of a weak stratum by a bedding fault to chemical decomposition without mechanical aid. Blankets are sometimes overlain or underlain by sheets of igneous rock which have been intruded earlier into the sedimentary series, and which, so far as the blankets are concerned, behave as massive irregular beds.

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[1] Unpublished MS.

Blankets are frequently mineralized and contain bodies of ore which may or may not be coextensive with the blanket itself. Such ore bodies will be termed *pay shoots*, as in the case of lodes.

Replacement ore bodies in limestone require no special definition. They embrace those ore masses, often of irregular form, which have molecularly replaced the limestone through the process known as metasomatism.

Stocks are those ore bodies commonly referred to as "chimneys." They are more or less solid masses of ore, roughly circular in plan, with their longest dimension nearly vertical. Their formation, while usually initiated by two or more intersecting fissures, is accompanied by considerable metasomatic replacement of the country rock.

LODES.

FISSURE SYSTEMS.

Partly on account of the oxidation of their upper portions, but more largely through the concealment of their outcrops by landslides and wash, the lodes of the Rico district are very poorly exposed on the surface. Furthermore, as will be shown later, several of the lodes never did extend to the surface. These conditions make a comprehensive study of the fissures, with reference to the area as a whole, very difficult. Certain groups of fissures, such as those in Newman or Nigger Baby hills, may, through the aid of underground workings, be studied in some detail, but the identification or comparison of the fissures of any such local group with those of another group is rarely satisfactory. Such comparisons usually bring out marked differences, but the transitions connecting these differences are nearly always concealed from view.

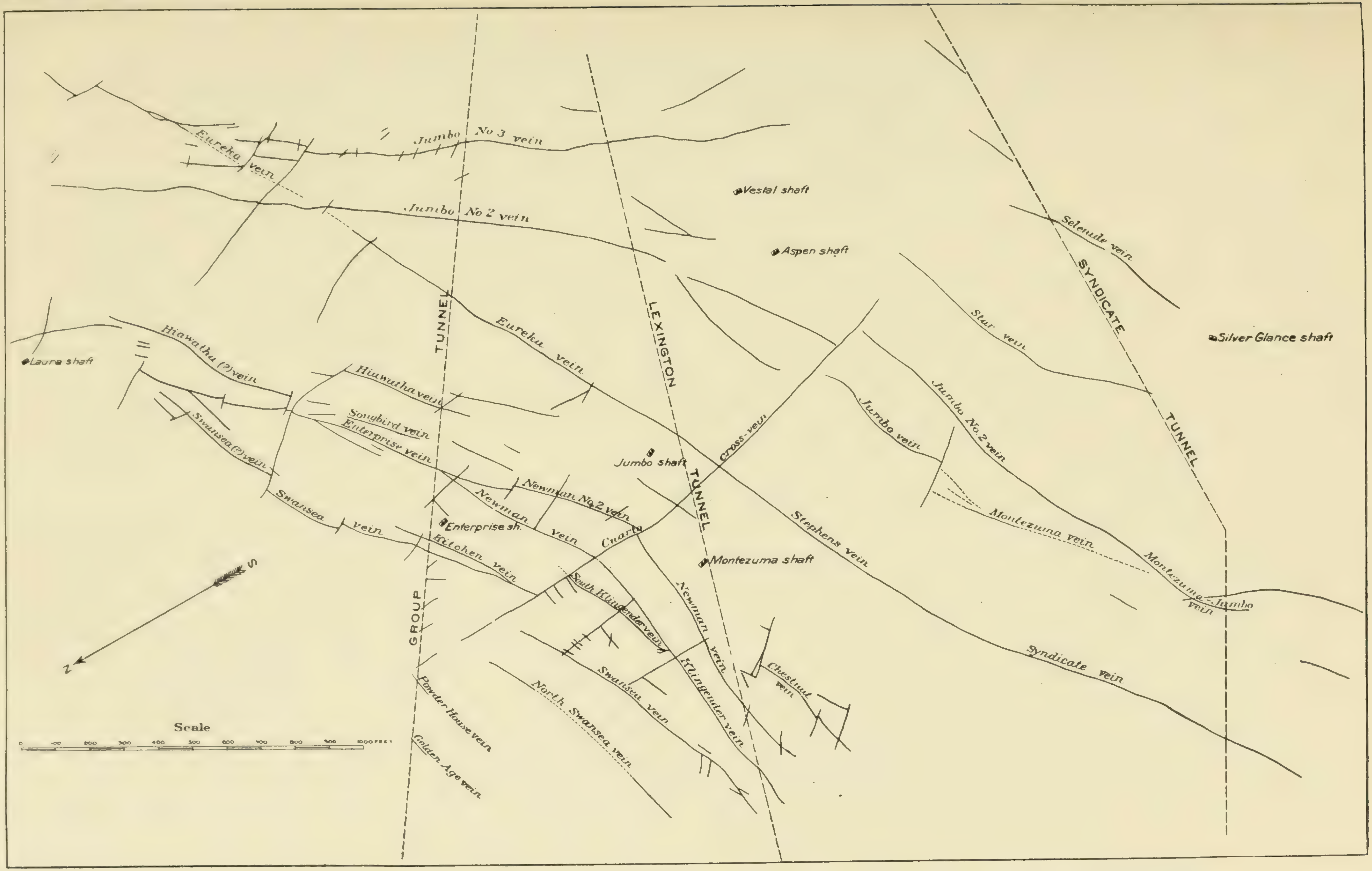
The distribution of the lode fissures is closely connected with the general geological structure of the district. They are most abundant in the central portion of the area and decrease in number and importance toward the periphery of the dome-like uplift of strata from which the Rico Mountains have been carved. The most important fissures are undoubtedly those of Newman Hill. Second in number and productiveness are those of Nigger Baby Hill. Other notable fissures are connected with the great dislocation known as the Blackhawk fault. Some of these seem to have played an important part in the mineralization of C. H. C. Hill, but so disturbed and buried are they by landslide material that any thorough study of them is impossible. Many other lode fissures occur in Horse Gulch and on Expectation Mountain, but they are poorly exposed and none of them have proved of great importance as ore-bearing lodes.

The principal fissures of Newman Hill fall into two classes, distinguished by their strikes or trends, and by the character of the veins which fill them. The fissures of the more important class are characterized by strikes varying from about N. 25° E. to N. 65° E. They are locally known as "verticals" or "pay veins," but will be referred to in this report as *northeasterly* fissures. These are occupied by the ore-bearing lodes of Newman Hill, such as the Swansea, Kitchen, Enterprise, Songbird, Hiawatha, Eureka, Jumbo No. 2, Jumbo No. 3, Chestnut, Klingender, Montezuma, Selenide, Star, and other veins.

The second class of lode fissures encountered in Newman Hill is characterized by strikes ranging from nearly north and south to about N. 45° W. The fissures correspond to the "barren veins" or "cross veins" of the Newman Hill miners, but will be referred to in this paper simply as *northwesterly* fissures. They are not themselves ore bearing, although, as will be shown later, they exercised an important influence upon the deposition of ore in an overlying blanket. Some idea of the disposition of the two sets of fissures may be gained from Pl. XXIX, compiled from underground workings.

The northeasterly fissures are usually clean, simple fractures, nearly vertical, or dipping southeastward at high angles. They range in width from a mere crack up to 2 or 3 feet; but a width of 18 inches is rare, and the average is probably not much over 6 inches. They traverse sandstones, shales, and limestones belonging to the lower division of the Hermosa formation. These beds dip somewhat east of south at a general angle of from 10 to 15 degrees. The fissures were originally opened by normal faulting, of which the known throw has in no case exceeded 10 feet, and is usually much less.

The fissures are limited above by the main Newman Hill blanket, commonly known as the "contact." At a varying distance below it, usually less than 20 feet, the fissures begin to split up into smaller fractures (fig. 43). This division into countless small irregular fissures



MAP SHOWING SOME OF THE MORE IMPORTANT LODE FISSURES IN THE ENTERPRISE, NEWMAN, AND RICO-ASPEN MINES.

is particularly noticeable within a series of shales and very thin-bedded sandstones which underlie the blanket. Some fissures are known above the blanket, but they contain no ore and can not be identified with those below it.

The conditions which limit the northeasterly fissures in length are not well known, as apparently none of the lodes have been worked to the point of disappearance. Toward the southwest some of the more continuous ones probably reach and are cut off by the Deadwood fault. Toward the northeast the fissures very likely die out before Silver Creek is reached. Several transverse faults are known to intervene between the workings of the Enterprise mine and Silver Creek, but in spite of these the productive northeasterly fissures should have been recognized in the Onamo, Pro Patria, Fickle Goddess, or Hibernia tunnels, did they preserve their strength and regular character northward. Several northeasterly fissures are cut in the Fickle Goddess and Pro Patria tunnels, but they show no resemblance to the productive lodes farther south. It is probable that the prominent northeasterly fissures known in the Enterprise, Newman, and Rico-Aspen mines do not persist across the thick intrusive sheet of monzonite-porphyry which rises up over the northern slope of Newman Hill (see Pl. XLI), and in which is sunk the Skeptical shaft. They either die out before reaching it or are deflected into other courses.

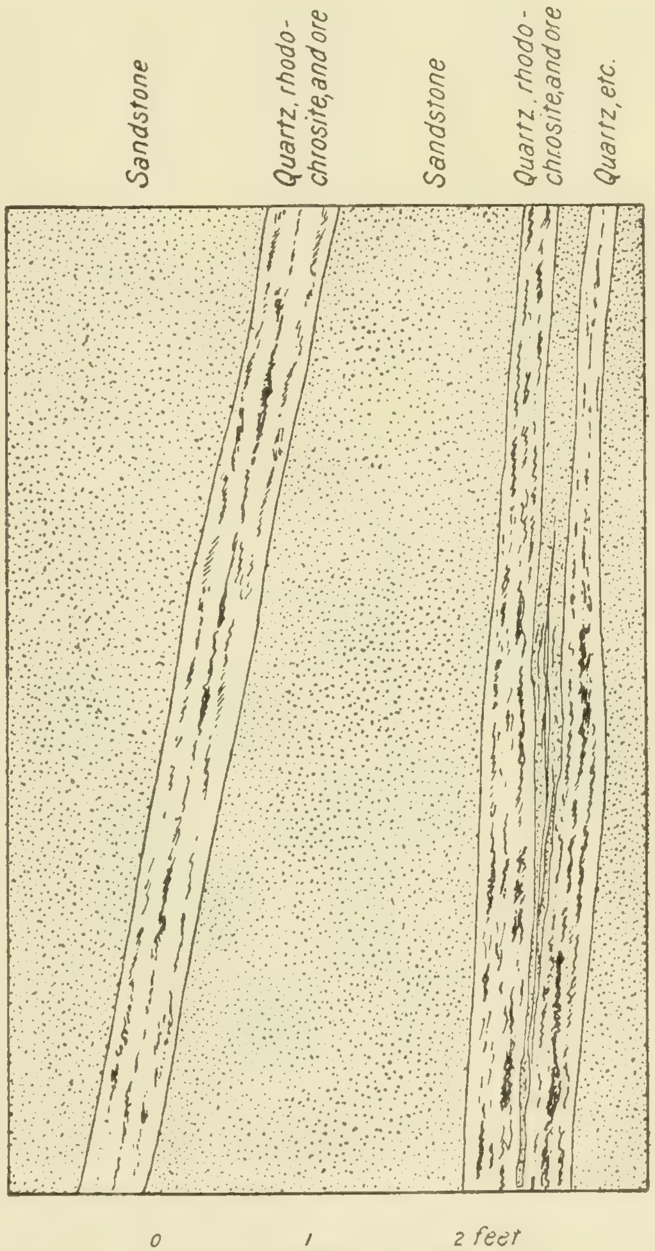

Sandstone
Quartz, rhodochrosite, and ore
Sandstone
Quartz, rhodochrosite, and ore
Quartz, etc.
0
1
2 feet

FIG. 40.—Cross section of Jumbo No. 3 lode, north breast, intermediate level, Enterprise mine.

The most persistent and regular of all the Newman Hill fissures is that worked for a distance of over 3,000 feet under the names of the Eureka, Stephens, and Syndicate veins. On the north this fissure joins the Jumbo No. 3 fissure, which, from the supposed junction point northward, has the direction of the Eureka lode and not of the Jumbo No. 3 proper (see Pl. XXIX). This Jumbo No. 3-Eureka fissure continues northeastward to the limits of the Enterprise ground, splitting near the breast into a sheeted zone (fig. 40) carrying rather low-grade ore.

None of the northeasterly fissures have been explored to great depth, but the section afforded by the Lexington tunnel, about 450 feet below the Newman Hill blanket, shows that the fissures are smaller at this depth than in the workings above.

The northwesterly fissures of Newman Hill are more abundant than the northeasterly. But owing to the fact that they contain no workable ore they are seldom drifted on and are consequently not so well exposed as the latter. Their dips range from vertical to about 40°, and may be northeastward or southward, the former being more common. The average dip is lower than that of the northeasterly fissures.

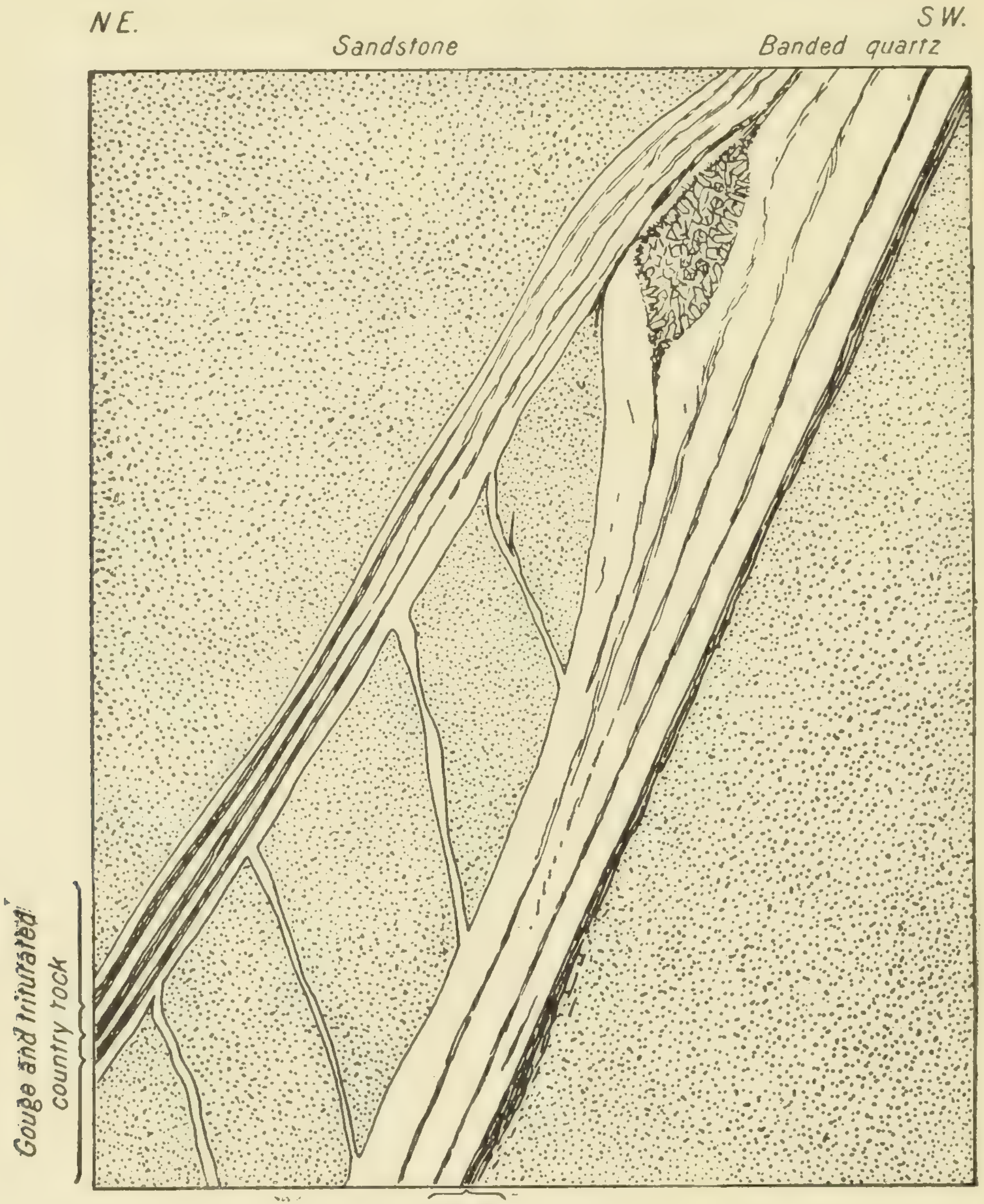


FIG. 41.—Cross section of the James cross vein, south breast of James drift, Newman mine.

They vary greatly in width, from a mere crevice up to 3 or 4 feet. Although often simple fractures, they very freqently show more complex form, as shown in fig. 41. These fissures appear to have been opened by normal faulting, and in some cases are reported to have faulted the overlying blanket to the extent of 25 feet throw. Vertical displacement to this amount is, however, rather exceptional. Moreover, as will be seen later, the structure of the northwesterly lodes shows that a considerable part of the observed faulting may have taken place since the fissures were first formed.

In the Union-Carbonate mine, on the northern spur of Dolores Mountain, the fissures show few resemblances to those of the more southerly portion of Newman Hill. The productive northeasterly fissures are not developed. Numerous other fissures are found striking from N. 60° W. to N. 75° W.—that is, more westerly than the northwesterly veins of the Enterprise mine. Fissures of this general trend are dominant on the northern slope of Dolores Mountain, as shown in the Union-Carbonate and Forest-Payroll workings.

Passing beyond Newman Hill, it is found that northeasterly fissures are of small importance in other portions of the district. Several have been worked at the eastern base of Expectation Mountain, between Sulphur Creek and Iron Draw, in the N. A. Cowdrey, Tomale, Argonaut, and Bancroft mines. The strikes of these fissures range from N. 40° E. to N. 60° E. They are fairly abundant, but small, rather irregular, and apparently not very persistent.

On Nigger Baby Hill the economically important fissures are northwesterly in trend. Such are the Hope, Cross, Grand View, Phœnix, and Butler veins. Near the top of the hill and on the western slope the average strike is N. 30° W. and the average dip northeasterly at about 25°, although the Cobbler vein is steeper. As these fissures are followed downward their dips are found to increase. The Phœnix vein, with dips sometimes as low as 15° in the upper workings, steepens to 45° in the lower tunnels, or the southern slope of the hill. The Cobbler vein is practically vertical on the Phœnix No. 1 level, and the Butler veins, outcropping still higher up the hill, dip northeasterly at about 70° on the Alma Mater level. The strike of the fissures is also found to be more westerly as they are followed southeast, toward Silver Creek. The Nellie Bly vein is rather exceptional in striking nearly east and west. If, as supposed by some, it is the same as the Grand View vein, it shows a change of course in the latter amounting to over 60°.

The Iron lode, on the southeastern slope of Nigger Baby Hill, strikes N. 16° W. and dips easterly at about 75°. Its trend is thus more northerly than the majority of the lode fissures on the hill.

The Hope, or Grand View, Cross, Phœnix, and Nellie Bly fissures are notable from the fact that their strikes are very nearly parallel to those of the beds which inclose them, while their dips, although generally slightly steeper in angle, correspond in direction to those of the strata. Consequently these fissures cross the bedding planes at a very acute angle, causing the lodes, particularly in the upper part of the hill, to closely resemble the form of deposit that has been termed a blanket.

The main fissure, upon which are located the Blackhawk, Argentine, and Uncle Ned mines, has a general course of N. 40° W. and dips northeast at angles varying from 50° to 80°. The geological work of Cross and Spencer has shown that this fissure probably constitutes a part of a pronounced zone of faulting which they have called the Blackhawk fault. The same fissure passes under the landslide of C. H. C. Hill, and probably corresponds to the Pigeon lode, or so-called "big fissure" of that hill, and with the C. V. G. lode at Burns. It is quite possible also that the A. B. G. lode, on the west side of the river, is on a branch of the same fault, for, as the geological map shows, it occupies a fault fissure. Details of the Blackhawk fissure are difficult to obtain. It is undoubtedly the largest and most persistent in the region, attaining in places a width of over 40 feet. It is not likely, however, that any open space of this width existed at any one time. The great width of the lode at certain places is due to the passage of a simple fracture into a sheeted zone, and also to repeated reopenings and fillings along the same zone of fracture.

Intimately connected with the Blackhawk fissure are several fissures striking about N. 70° W. and falling into the main fissure on its northeast side. Such are the Little Maggie and Alleghany veins, the former dipping northeast at about 60°, while the latter dips southwest at about 70°. Cross and Spencer have regarded these fissures as probably structural faults,[1] but they are small, simple fractures which have not effected any discoverable faulting of the beds which they traverse. Just northeast of them lies a fissure of similar trend, but of no economic importance. This, as shown by the geological map (Pl. XLI), is a distinct fault.

On the northwestern slope of Telescope Mountain, north of C. H. C. Hill, are several northwesterly fissures, usually with steep southwest dip. The two upon which are located the Golden Rod and Leap Year claims are strong and persistent fractures.

Northwesterly fissures also prevail in Horse Gulch, but they are poorly exposed and not at present producing ore. Such are the fissures of the Mohawk, Christina, Belzora, Caledonia, Utah, and other unworked prospects. They are prominent also in the Little Leonard mine in monzonite on the eastern slope of Expectation Mountain.

In addition to the Nellie Bly lode fissure (not the Nellie Bly fault) on Nigger Baby Hill, which has a low northerly dip, nearly east and west, approximately vertical fissures are known in the Lily D. mine, on C. H. C. Hill; in the Calumet mine, north of Piedmont; in the Aztec mine, in Aztec Gulch; in the California and Zulu Chief mines, near the head of Iron Draw; and apparently also in the Eighty-Eight mine, on Silver Creek.

It appears from the foregoing that the northeasterly fissures which have proved so productive in Newman Hill are characteristic of but a limited portion of the district, comprising roughly the southern half of Newman Hill and that part of the base of Expectation Mountain

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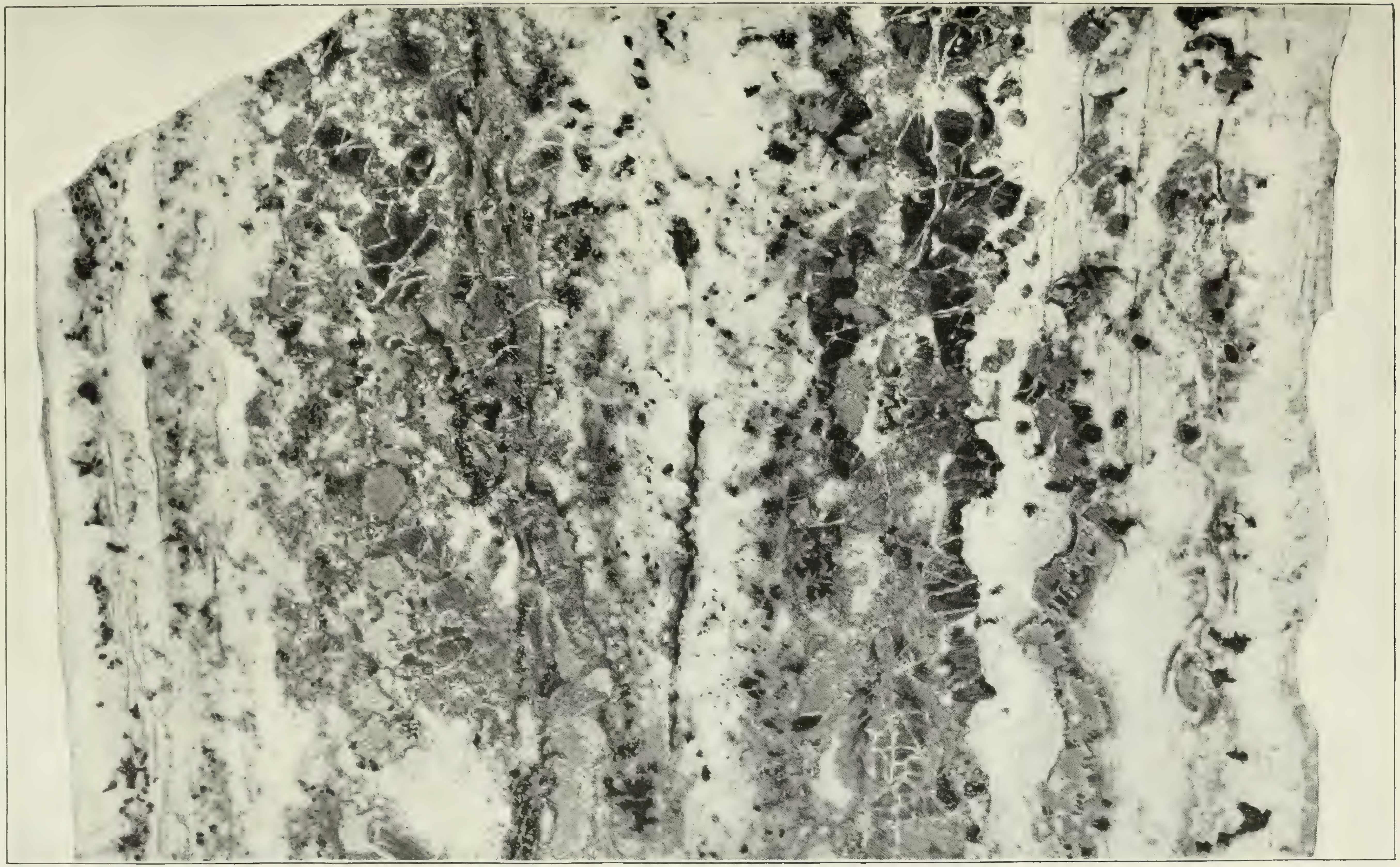
[1] Loc. cit., p. 118.



SECTION OF A RICH PORTION OF JUMBO NO. 3 VEIN, ENTERPRISE MINE.

The illustration, which embraces the entire width of the vein (9 inches), shows the usual banding characteristic of the lode ores of Newman Hill. It does not, however, reveal the relative distribution of galena, sphalerite, and chalcopyrite in the ore bands

lying between Sulphur Creek and Iron Draw. Fissures of general northwesterly course, on the contrary, are abundant, not only in Newman Hill but over the entire central portion of the area. Between northeasterly fissures and northwesterly fissures the separation is fairly definite; but between northwesterly fissures on the one hand, and east-west fissures, and in a few cases north-south fissures, on the other, the distinction is less sharp. In the main the fissures are simple and of small or moderate size. With a few notable exceptions they either show no evidence of having been opened by appreciable faulting or else the throw of the fault is small. Thrust faults (i. e., reversed faults) of any importance are not known, and the prevalent dislocation has plainly been normal in character.

STRUCTURE AND MATERIAL OF THE LODES.

The northeasterly fissures of the southern half of Newman Hill are usually occupied by simple fissure veins of banded ore, confined between sharply distinct walls of sandstone or shale. The general appearance of such a vein is shown in Pl. XXVIII, *B*, from a photograph of the Jumbo No. 3 vein (Enterprise mine), which at the point chosen for illustration has a width of nearly 3 feet, but is poor in ore. The veins are usually "frozen" to their walls and the presence of gouge is the exception rather than the rule.

The vein filling consists of quartz, rhodochrosite, sphalerite, galena, chalcopyrite, pyrite, together with argentite, proustite, polybasite, and other highly argentiferous minerals. These various minerals have been so deposited within the fissure as to give a pronounced but rather irregular banding to the veins, as shown in Pl. XXX, which is from a section of the Jumbo No. 3 vein, showing a width of 9 inches of good ore. On fresh exposures the alternating bands, in which rose-pink rhodochrosite, white quartz, rosin-yellow sphalerite, and the various metallic minerals are present in different proportions, give to these veins a striking and unusual beauty. No orderly or constant sequence of mineralogical deposition can be determined from the banding. Usually quartz and rhodochrosite, arranged in irregular bands and inclosing more or less pyrite, chalcopyrite, sphalerite, and galena, occur next to the walls; then follow ribbons in which sphalerite and galena predominate; and finally, along the middle of the vein, there is usually a zone of comb structure, or vugs, consisting largely of quartz and of the high-grade argentiferous minerals. The last are particularly abundant in the quartz vugs, which nearly always occur along the medial plane of the vein, and sometimes along planes near the wall.

In most cases the filling of the northeasterly fissures from the walls to the medial zone of vugs appears to have been a continuous process; but in other instances the fissure, after having once been filled, has been slightly reopened along one or both walls and the resulting space freshly filled, usually with practically barren quartz. This is illustrated in Pl. XXXI, also from the Jumbo No. 3 vein. The vein, here 4½ inches wide, appears to have undergone two or more successive reopenings, each to the width of about half an inch.

Although the northeasterly lodes of Newman Hill are typified by the simple fissure vein, yet they occasionally split up into more complex forms, such as sheeted zones or stringer lodes. The transformation of the veins to masses of small, irregular stringers, near their junction with the Newman Hill blanket, has already been referred to, and will be more fully described elsewhere (pp. 290–291).

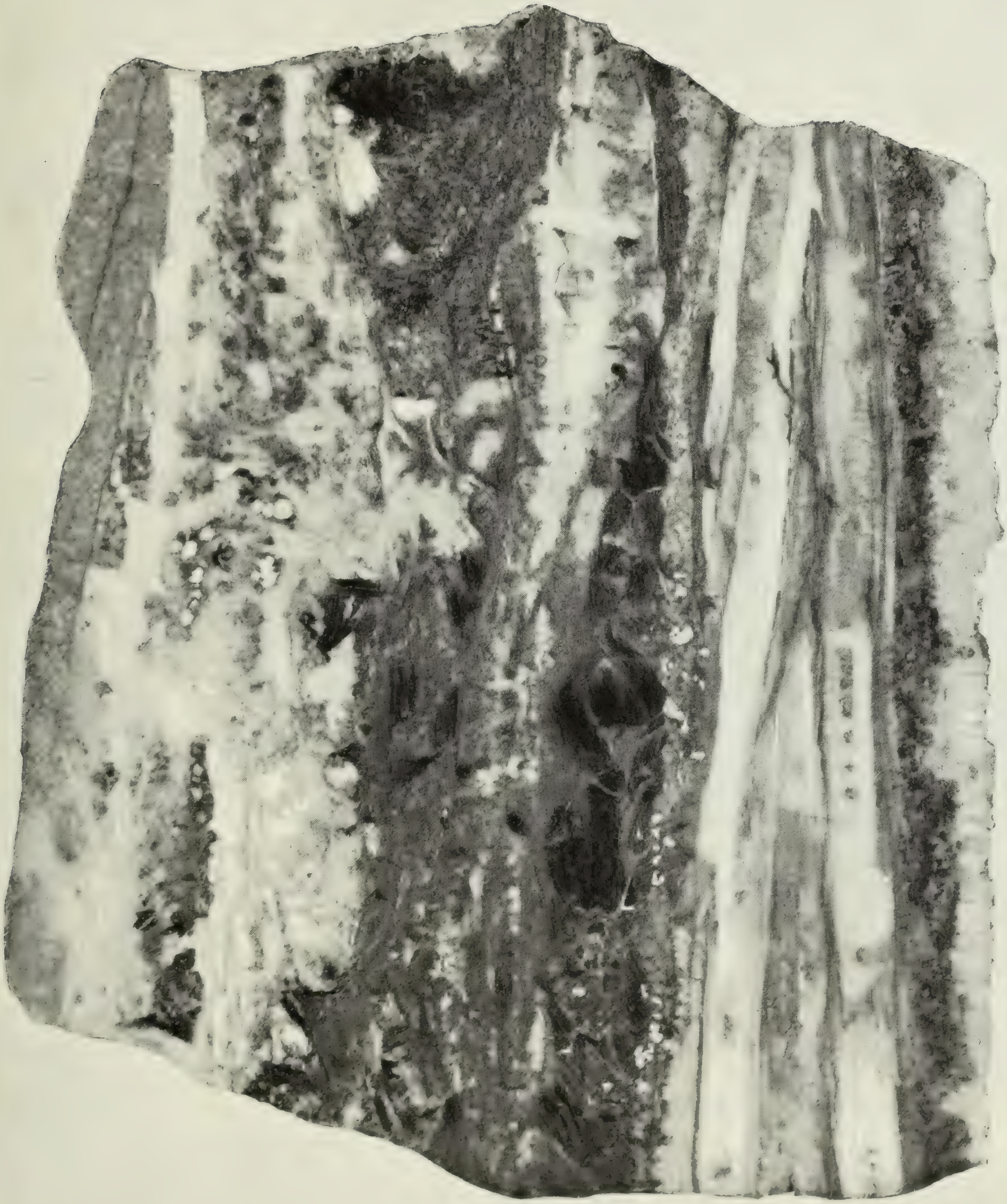
Toward the north the material of the Newman Hill northeasterly veins changes. Such veins as have been followed to the Laura crosscut (see Pl. XXXVI) show a notable diminution in the value of their contents. North of the Laura crosscut lies some ground within which the veins have not been much explored; but a little farther north, in the Pro Patria, Fickle Goddess, and other tunnels, the only northeasterly veins found carry little but quartz and pyrite and are of too low grade to pay for working.

The northeasterly veins exploited in the Cowdrey, Tomale, Argonaut, and Bancroft mines, on the west side of the Dolores River, differ materially in their filling from those in Newman Hill. They contain low-grade argentiferous galena, with much sphalerite and pyrite. The gangue is quartz with no rhodochrosite. These veins are generally small, and adherent, or "frozen," to their walls. They frequently split into small, irregular stringers which die out in the country rock. The striking banded structure of the Enterprise lodes is lacking in these veins of like trend on the west side of the river.

The northwesterly lodes of Newman Hill form a notable contrast to those of northeasterly trend. They are filled with white quartz, sometimes containing pyrite, but never any ore in commercial amounts. As opposed to the usual solidity of the northeasterly veins, entire sections of which, with adhering wall rock, can frequently be taken out as specimens, the northwesterly lodes are almost invariably crushed, and accompanied by seams of gouge. The result of this crushing, in extreme cases, is a loose mass of quartz and clay that can be excavated with pick and shovel.

In the Newman mines, where the northwesterly lodes are better exposed and often less shattered than elsewhere, they frequently show rather complex structure, and are often, properly speaking, stringer lodes (see fig. 41).

A banded structure, in which white quartz alternates with thin, shadowy, gray bands, is common in the more solid portions of the northwesterly lodes, and is represented in fig. 41. The dark bands are partly solidified, thin plates or skins of sandstone or shale. They represent portions of the wall which adhered to the vein already formed



SECTION OF A NARROW PORTION OF THE JUMBO NO. 3 VEIN, ENTERPRISE MINE. NATURAL SIZE.

On the right side is shown later banding, due to reopenings of the fissure.

upon successive fresh openings. Such reopenings have in some cases been many times repeated. At least five renewed depositions of quartz, separated by thin, shaly partings, were counted in a portion of the James cross vein, in the Newman mines. The average width of these individual veinlets of quartz is about a quarter of an inch.

Passing to the northern part of Newman Hill and to the northern slope of Dolores Mountain, the more westerly lodes, which there predominate in the Union-Carbonate and Forest-Payroll mines, show less crushing or shattering. They have also furnished a little ore. The Forest lode is composed of about a foot of quartz and low-grade sphaleritic ore. The latter occurs only in bunches.

On the northern spurs of Blackhawk Peak, the Little Maggie and Alleghany lodes, which also have a northwesterly course, are simple fissure veins, but are so deeply oxidized that their original filling and structure can only be surmised. The Blackhawk lode itself is difficult to describe or define, as it apparently consists of several nearly parallel veins of quartz, forming part of the Blackhawk fault zone. These veins are composed of practically barren, massive quartz, showing no peculiarity of structure. There are no other accessible workings on this lode until C. H. C. Hill is reached, where its probable extension, the Pigeon lode, is encountered in the Logan and Pigeon mines. Here it greatly resembles the northwesterly lodes of Newman Hill, but is on a much larger scale. Where seen in the Pigeon crosscuts, it shows a width of 40 feet and consists of several stringers of quartz and pyrite separated by sheets of country rock. Some of the individual veins of this sheeted zone are 5 feet wide, composed of white, barren quartz and numerous vugs. The whole lode is greatly shattered and is accompanied by much soft gouge. In the Logan workings, the lode shows a width of 12 feet and contains masses of soft, crumbling pyrite. Neither the Blackhawk nor the Pigeon lodes carry any workable ore as far as known, although some appears to have been extracted from that portion of the fissure which traverses the Uncle Ned ground, on Telescope Mountain.

The C. V. G. lode, at Burns, not now accessible, is probably the same as the Pigeon. The A. B. G., on the west side of the river, is a strong vein up to 6 feet in width, carrying streaks of galena, sphalerite, and pyrite in a gangue of quartz and calcite. The vein is accompanied by considerable gouge, indicating movement which probably accounts in part for the structural fault shown on the map (Pl. XLI).

On Nigger Baby Hill the northwesterly fissures are distinguished by an entirely different type of vein from those on Newman Hill. They are prevailingly simple fissure veins of moderate size. In their upper portions they have undergone decomposition of a kind to be more fully described hereafter, but in their deeper, unoxidized portions these veins contain a relatively low-grade sphaleritic ore in a calcite matrix or gangue. Quartz is either wholly lacking or is very subordinate in amount. The calcite varies in coarseness of crystallization. The coarser varieties, showing distinct cleavage faces of dull white or slightly pinkish calcite, were noted in the Iron lode and the Butler No. 2 vein. Finer-grained facies, often slightly yellowish in tint and closely resembling in texture an ordinary limestone, occur in the Phœnix and main Butler veins. The character of the gangue, however, often varies from place to place in the same vein. The proportion of ore minerals to gangue is also extremely variable, ranging from nearly barren calcite on the one hand to nearly solid masses of galena, sphalerite, chalcopyrite, and pyrite on the other. Although the mineral rhodochrosite has not been recognized in these veins, there is good reason for supposing the calcitic gangue to be more or less manganiferous.

Banding is well developed in a branch of the Phœnix lode, on the No. 3 level. The vein is here about 4 inches wide, made up of alternating bands of ore and gangue, varying from 0.1 to 1 inch in thickness. It was from the decomposed upper portions of these relatively low-grade calcitic veins that the bulk of the ore from Nigger Baby Hill has been obtained.

Little can at present be learned concerning the structure of the numerous northwesterly lodes of Horse Gulch, owing to the abandonment of most of the workings upon them. The lodes of the Mohawk, Zenith, and Marriage Stake claims contain practically no vein filling, but are zones of silicification and of impregnation by pyrite, along fissures in monzonite-porphyry. The dump of the Lackawanna shows that this prospect followed a lode containing abundant manganiferous carbonate. Most of the Horse Gulch lodes evidently contained much pyrite, in association with which occurred bunches of saleable ore.

Development on the northwesterly lodes lying north of C. H. C. Hill is not such as to afford much information in regard to their structure. The Leap Year lode, in places 15 feet wide, is in part a silicified breccia zone in sandstones and shales, and in part a stringer lode. It contains a little pyrite and an occasional bunch of galena in much white quartz. The Hureka vein, consisting of about a foot of white, somewhat cellular quartz next the foot wall, and 2 or 3 feet of crushed rock, iron oxide, and clay next the hanging wall, has been superficially prospected and found to contain a little gold. The Golden Rod is a large quartz vein containing numerous fragments of country rock, with pyrite and bunches of galena ore.

Northwesterly fissures are abundant in the Little Leonard mine on Expectation Mountain, but they contain little besides soft gouge.

The structure and filling of the nearly east-west lodes of the Nellie Bly lode fissure, on Nigger Baby Hill, are found to be in every way similar to those of the northwesterly veins on the same hill, such as the Hope or Grand View. The Last Chance lode, lower down on the south slope of the hill, is an irregular fissure vein between walls of altered porphyry, impregnated with pyrite. The vein itself is composed of quartz, pyrite, and chalcopyrite. The Aztec lode, supposed to be on the line of the Nellie Bly fault, consists of banded quartz, about 3 feet in width where seen, accompanied by much crushed and mineralized country rock on each wall (see fig. 62, p. 365). The quartz vein, which apparently owes its banded structure in part to repeated openings and fillings of the original fissure, contains no ore. On the south or foot wall the vein is accompanied by a breccia zone, about 2 feet in width, of mineralized calcareous shales. These pass, with no distinct wall, into less disturbed beds of shale and limestone, which are partly replaced by pyrite and traversed by small stringers of quartz for a distance of 5 feet or more. A very similar breccia, at least 5 feet in width, occurs on the hanging wall, and contains bunches of ore, consisting of pyrite, chalcopyrite, galena, and sphalerite. In the Zulu Chief mine, near the head of Iron Draw, a lode is cut, exhibiting a structure similar to that of the Aztec (see pp. 364–365). It is likely that the two occupy the same fissure. The Calumet lode, supposed to correspond to the Last Chance fault, is a large irregular vein up to 5 feet in width, filled with quartz containing bunches of pyrite. There are no regular walls to the fissure, and the country rock is much decomposed. The whole lode is crushed and disturbed by recent movements.

The foregoing résumé shows that, taking the region as a whole, fissures of like trend are not necessarily characterized by similar ores or by corresponding structures. The miners who first worked in Newman Hill were naturally struck by the contrast between the local richness of the northeasterly veins and the poverty of the northwesterly fissures. They distinguished the two as "pay veins" and "barren veins," and this terminology has obtained a certain currency throughout the district. The adoption of richness and poverty as criteria for classifying the lodes of the region is misleading, particularly as different portions of a single lode would thereby frequently be placed in supposedly distinct classes.

CHANGES IN THE ORE WITH DEPTH.

There are probably few more striking features connected with the Rico ore deposits than the very limited vertical range of the ores. With the exception of the Little Maggie and Alleghany veins, and those of Newman and Nigger Baby hills, none of the lodes in the district have produced much ore, or have been explored to any considerable depth. Such ore as has been found occurred in isolated pockets, or is so low in grade that the various spasmodic attempts to work it have been successively abandoned. Low-grade pyritic ores extend to greater depths than are anywhere reached in the district, but no success has yet attended attempts to exploit them. In the cases of the Little Maggie, Alleghany, and Nigger Baby Hill lodes, the lower limit of the workable ore has thus far been found to correspond with the bottom of the zone of oxidation. The rich ore is here due to purely secondary processes, which will be described in a later section.

In the northeasterly lodes of Newman Hill, however, there is a most decided change, which antedates all superficial oxidation. Unlike secondary enrichments due to ordinary oxidizing processes, the depth at which the Newman Hill veins change their character bears no relation to the topographic surface, but is more or less constant with reference to an overlying blanket. For a maximum distance of about 150 feet below this blanket (the Newman Hill "contact") the northeasterly lodes contain pay shoots of rich ore, such as has been described on pages 261–262. Below this depth the valuable silver minerals disappear; galena, sphalerite, and rhodochrosite vanish; and the veins, which above produce ore carrying many hundred of ounces of silver per ton, change to practically barren quartz and pyrite. So far as their material is concerned they become indistinguishable from the northwesterly lodes. The practical reality of this change is well brought out in the series of longitudinal sections through the veins of the Enterprise mine, shown in Pl. XXXVII. In the Lexington tunnel, which crosscuts the Newman Hill lodes at depths varying from 350 to 550 feet below the blanket, they are found to be small and practically barren, consisting of quartz and a little pyrite.

OXIDATION OF THE ORES.

In the southern part of Newman Hill, as no lodes are worked above the Newman Hill blanket, and as the latter is protected from the free access of surface waters by an impervious bed or "roof" of shale, oxidation has played but a minor part in the development of the ore bodies. In the Union-Carbonate mine some oxidized ore was mined from a northwesterly fissure. This ore was near the surface and extended to a depth of 30 or 40 feet below an overlying blanket, also oxidized. On Nigger Baby Hill, however, and in the Little Maggie and Alleghany lodes, descending surface water has been the effective agent in producing workable deposits of ore.

The depth to which oxidation has penetrated in Nigger Baby Hill is apparently variable. Owing to the steep sides and faulted structure of the hill the permanent ground-water surface is low, and oxidation has probably nowhere extended down to it. The process has been irregularly limited by very local physical and chemical factors and by time. Judging by the extent of the old stopes it appears probable that complete oxidation extends for about 200 feet from the present surface of the hill near its summit, growing less on its flanks.

The process of decomposition was undoubtedly greatly facilitated by the fact that the veins contain a calcitic and not a quartzose gangue. In the initial stages of alteration the impure calcite, containing more or less carbonate of manganese, turns yellowish and is speckled with black dots consisting chiefly of oxide of manganese. As the process goes on these become more numerous and the vein is traversed by soft seams of hydrous oxides of iron and manganese. Finally all original structure disappears and the once solid vein becomes a soft mass which, when seen underground in the moist condition, is black and sooty, but which dries to various dark-brown tints. A chemical analysis of some of this material from the Nellie Bly vein is given below. The substance dries to a very dark-brown powder, soiling the fingers like soot.

It was prepared for analysis by passing through a coarse screen, whereby some irregular quartzose particles were removed, leaving a fairly homogeneous powder.

Chemical analysis of oxidized material from Nellie Bly vein, Nigger Baby Hill.

[W. F. Hillebrand, analyst.]

Constituent.	Per cent.
SiO_2	15.25
Al_2O_3 with a little P_2O_5 and TiO_2	5.73
Fe_2O_3	13.42
MnO_2	33.77
ZnO	4.75
CaO	2.58
MgO	.97
H_2O at 110° C.	22.81
H_2O above 110° C.	
CuO, CO_2, alkalies, etc.	.72
Total	100.00

The foregoing analysis shows that the material is composed chiefly of the hydrous oxides of manganese and iron. The silica is probably present principally as quartz in loose, spicule-like bunches of minute crystals and partly as a hydrous silicate of alumina. The zinc oxide has resulted from the oxidation of sphalerite. The striking features brought out by the analysis are the small amount of lime left in the formerly calcareous vein and the large quantity of manganese present. Although typical, as far as appearance goes, of the oxidized vein matter of Nigger Baby Hill, this particular sample is plainly not an ore.

Not all of the oxidized portions of these veins are workable, but only those in which silver, either native or as cerargyrite or embolite, and sulphate, carbonate, or oxide of lead have been concentrated. Such rich portions are often detected by the presence of small bright specks of malachite or azurite.

The alteration of the upper portions of the Little Maggie and Alleghany veins has been somewhat similar to that described. The Little Maggie vein, however, seems to have contained more copper than is present in the Nigger Baby Hill veins, and some residual kernels of pink rhodochrosite were noted.

RELATION OF THE LODES TO THE STRUCTURAL FAULTS.

In their work on the general geology of the Rico region Cross and Spencer found the structure of the district to be greatly complicated by faulting, the displacement in some cases amounting to several hundred feet. Owing to the frequent concealment of outcrops by landslides and wash these faults are often very poorly shown on the surface, and to properly delineate and interpret them constituted a highly complex geological problem. The solution of this problem, as indicated on the geological map (Pl. XLI), reflects high credit upon these investigators.

Upon taking up the study of the lode fissures, the question of their possible relations to the important structural faults established by the geological mapping was naturally considered. It was found that the connection between them is neither so close nor so obvious as on a priori grounds might be expected.

The productive lodes do not occur in the fissures of considerable faults. Out of the 50 or more fault fissures drawn upon the geological map not one has been shown to contain any large bodies of ore. The Blackhawk lode, which does not itself contain workable ore so far as known, is very close to a large fault, but it is by no means certain that it fills the actual fault fissures. The same might be said of its probable continuation, the Pigeon lode, in C. H. C. Hill. The A. B. G. lode at Burns is possibly on a branch of the Blackhawk fault. It contains some low-grade ore, which, however, has never been worked on a commercial scale. The Nellie Bly fault certainly does not coincide with the Nellie Bly vein, but appears as a close, inconspicuous fissure a few feet south of the latter. It is possible that the western extension of this fault passes through the Aztec and Zulu Chief lodes, but these properties can scarcely be classed as productive. The Last Chance fault, although taking its designation from a prospect of that name, is certainly not identical with the Last Chance lode fissure. It is shown on the map as passing through the workings of the Calumet, an unproductive prospect on the west side of the river.

The question of the coincidence of faults and lodes may be justly summed up in the statement that the most productive lode fissures of the district show very little faulting along them while fault fissures of sufficient extent to be structurally important contain little or no ore. It is but fair to remark, however, that the fault fissures have been scarcely prospected.

Considerable structural faults may also be important in displacing lodes which they cross. It is highly probable that the Deadwood fault, south of Newman Hill, cuts off the Newman Hill blanket and lodes, throwing their southern continuations downward and westward. A zone of faults passing down the west slope of Dolores Mountain, past the Laura shaft, has probably offset the same lodes on the north. Neither of these points, however, could be determined underground at the time of visit.

The Nellie Bly fault, which passes over the nose of Nigger Baby Hill and brings up the massive limestones of the medial division of the Hermosa on the south until they abut against the Rico beds on the north,[1] passes through the workings of the Grand View and Iron mines, without, as far as can be seen, interrupting the Phœnix, Grand View, or Iron veins. It seems necessary to conclude that these veins are of later origin than the fault.

RELATIVE AGES OF THE LODES.

The question of the relative ages of the northeasterly and northwesterly lodes of Newman Hill is of theoretical and practical importance. Farish[2] and Rickard[3] have both discussed it, and reached conclusions not entirely in harmony. Farish, after describing the relations observed by him, says:

> A consideration of these irregularities naturally suggests a speculation concerning the relative ages of the two vein systems. In this connection I must confess that, from the complexity of the problem, I have not been able to arrive at positive conclusions. Reasoning from the occurrence of the sharp faults in the "vertical pay veins"—the dislocation being absolute—and the unbroken trend of the "cross veins," the inference would be drawn that the latter are, relatively, the younger. Whatever mistrust arises from such a deduction is occasioned by the observed deviation of the "vertical pay veins" from their normal course for considerable distances to a parallelism with the intersecting "cross veins" within the walls of the latter. On the assumption, however, that all of the "vertical pay veins" when disturbed by intersecting "cross veins" were originally faulted, and that the faulting fissure in some instances—prescribed by local influences—furnished a connecting channel for the mineral solutions circulating in the faulted vein, these phenomena are susceptible of reasonable interpretation. I am at least strongly inclined to favor this view.

Rickard, on the other hand, maintains that the northwesterly fissures are younger than the northeasterly lodes, and that the described deviations of the latter into the former are simply cases of drag, due to faulting.

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[1] See Cross and Spencer, loc. cit., p. 118.

[2] Loc. cit., pp. 158–160.

[3] Loc. cit., pp. 946–952.

Neither of the foregoing hypotheses is entirely satisfactory, although both contain partial truths. Neither Farish nor Rickard appears to have given due consideration to the various facts which must be included in any complete explanation. The observed phenomena that bear upon the question may be briefly summarized as follows, the reader being referred to the detailed accounts of the Newman Hill mines for their fuller description:

(1) The lodes of the two systems are distinctly different in trend (see Pl. XXIX).

(2) The northwesterly lodes are practically barren, whereas the northeasterly veins usually contain rich ore to a depth of about 150 feet below the Newman Hill blanket.

(3) The northeasterly veins sometimes show a later generation of quartz and pyrite.

(4) The northwesterly lodes, when not too much crushed, usually show banding due to repeated openings and fillings.

(5) The northeasterly veins are solid and often adherent to their walls; the northwesterly lodes are almost invariably crushed and accompanied by gouge.

(6) The northwesterly fissures generally cross the others without being themselves deflected.

(7) In some cases the northwesterly fissures fault the northeasterly lodes, but more commonly they pass through the latter without offsetting them. Marked changes in the value of the ore are said to occur at such crossings.

(8) A northeasterly vein is sometimes lost at the crossing of a northwesterly lode, as was the case with the Hiawatha on the 100-foot level of the Enterprise mine (p. 320) and the Chestnut and Newman veins in the Newman mines (pp. 332–334). It has been commonly assumed in such cases that the northeasterly vein has been faulted and offset for distances up to 175 feet. It is to be noted that the northeasterly vein is not always sharply cut off at the supposed fault, but small stringers are sometimes present, continuing on beyond the latter. Furthermore, the supposed offset of any one of the northeasterly veins cut by a northwesterly fissure is not always comparable in amount with the offset of the neighboring veins cut by the same fissure. Thus Rickard's diagram (fig. 47, p. 320) shows a northwesterly fissure offsetting the Hiawatha vein about 175 feet and the adjacent Songbird vein only 20 feet, both being nearly vertical veins.

(9) Northeasterly veins sometimes contract or divide into small stringers upon approaching a northwesterly lode (see fig. 51, p. 332).

(10) None of the lode fissures displace the overlying blanket more than 25 feet, most of them much less than this.

(11) In one case (that of the Jumbo No. 3 vein, Enterprise mine; see p. 321 and fig. 49) a northeasterly vein is known to turn into a northwesterly fissure for a short distance and then resume nearly its normal course. The deflected portion of the vein has been brecciated, and subsequently healed by white quartz, which was later shattered in its turn. In a few rare instances small northwesterly fissures have been observed occupied by the characteristic filling of the northeasterly lodes.

(12) The Eureka vein pursues a nearly straight course through the principal Newman Hill workings without being offset by the northwesterly fissures which cross it, and which are commonly supposed to have offset neighboring lodes, in some cases as much as 175 feet.

It is believed that the hypothesis which best reconciles the various observed facts is one which supposes the initial fractures, both northwesterly and northeasterly, to have been formed at practically the same time. Studies of vein structure in this and other regions show that lode fissures may not open to their full width until some considerable time has elapsed after the production of the first fracture. It is probable that in the network of intersecting and partly incipient fractures in Newman Hill the northeasterly fractures were as a whole the first to open sufficiently to permit vein deposition. If the northwesterly fissures are entirely of later date than the northeasterly veins, it is impossible to account for the fact that the latter occasionally follow the former for short distances, and that they sometimes die out or divide into stringers just as a northwesterly fracture is approached. That the ore changes abruptly in value at the crossing of northwesterly fissures, even where no faulting is perceptible, is strongly insisted upon by the miners and by the present superintendent of the Enterprise mine. It is best explained by supposing that the northwesterly fractures existed when the ore was being deposited in the more open fissures. If the northwesterly fissures were of altogether later date, and simply faulted the northeasterly veins, it should be possible to consistently match the faulted lodes on opposite sides of the dislocation. In many cases this is utterly impossible, for whereas some lodes are found to be slightly displaced and can be recognized and followed, others have no continuation beyond the fissure. Attempts to find and identify such continuations have led to absurdities, such as supposing that a fracture which throws the overlying blanket less than 24 feet and does not perceptibly offset the Eureka lode can offset one lode 175 feet and another, but a few feet away, only 20 feet.

On the other hand, unless it be allowed that the principal opening and filling of the northwesterly lodes was later than the ore deposition in the northeasterly lodes, it is impossible to account for the fact that the former cross the latter, and no good reason appears why both should not have been equally filled with ore. It is probable that the opening and filling of the northwesterly fissures was in part synchronous with the slight reopening and filling with barren quartz and pyrite observed in connection with the northeasterly lodes. It certainly corresponds to the partial brecciation and recementation by barren quartz of that portion of the Jumbo No. 3 vein, which follows a northwesterly fissure, and with the cementation of the fault-dragged fragments of the Swansea vein on the 100-foot level of the Enterprise mine (see p. 321).

Finally the shattered nature of most of the northwesterly lodes, and their constant accompaniment by seams of gouge, show that they have continued to be planes of more or less movement up to recent times. It is consequently impossible to determine how much of the observed moderate faulting along these fissures took place prior to their complete filling with quartz, and how much has taken place during the subsequent crushing of their veins.

If the foregoing view is correct, the development of the Newman Hill mines in recent years, in accordance with the hypothesis that the disappearance of a northeasterly vein at or near a northwesterly fissure is always due to the faulting, and that the faulted portion of the lode may be found offset over 100 feet to one side, has had no reasonable basis. Such a working hypothesis has certainly led to errors and confusion in identifying lodes on opposite sides of the northwesterly fissures. The practical consequences of adhering to this plan, however, have not been altogether disadvantageous, since it encouraged crosscutting, and led to the discovery of veins which were probably, in several cases, *not* the faulted continuations sought for.

It has been assumed in the foregoing discussion that lodes of like trend and similar character are of practically the same age. It is possible, however, that some of the northwesterly lodes may be earlier and some later than the northeasterly vein. While it would be difficult to disprove the latter view, it is not considered probable. Its acceptance would knock away the foundations which underlie systematic treatment of the lodes both on the theoretical and practical sides.

Passing beyond the bounds of Newman Hill, we find that the same age relationship exists between the northeasterly and northwesterly lodes on the west side of the Dolores River, between Sulphur and Iron creeks.

In other portions of the district, however, there is scant opportunity for determining the sequence of lode fissures of different trend. As already noted, the northeasterly lodes are absent or insignificant.

THE BLANKETS.

Enterprise blanket.—Of the various blankets occurring in the Rico district, the so-called Newman Hill or Enterprise "contact" is most important, and will be first described. The others will then be taken up, and their characteristic features so outlined as to emphasize points of resemblance or contrast, with reference to the most prominent type.

The Enterprise blanket is for the most part an unconsolidated breccia, occurring nearly midway between the top and bottom of the series of sandstones, shales, and limestones which make up the lower division of the Hermosa. It underlies the southern half of Newman Hill, but its extent is only approximately known. On the west it should outcrop along the hillside above the adits of the Rico-Aspen, Newman, and Enterprise mines, were it not for the thick cloak of wash which conceals the rock in place. On the east it conforms to the general southeasterly dip of the beds (about 15°), and passes under Dolores Mountain. At a distance of 3,000 feet, measured down the dip from the surface, the blanket becomes thinner; but its full extent in this direction is unknown. On the north it has not been followed far beyond the Laura shaft. Other blankets occur to the north in the Union-Carbonate mine, but none of them have been satisfactorily identified with the Enterprise "contact." On the south the blanket is cut off by the Deadwood fault. As it approaches the latter it turns down with a rapidly increasing southerly dip and passes out of reach from the levels of the present workings.

The blanket has been extensively exploited by the Enterprise, Newman, Rico-Aspen, and other mines, and is estimated to have produced at least a third of the entire output of the district. At present very few known bodies of ore remain, and the "contact" workings (see Pl. XXXVI) have been allowed to cave in.

The blanket rests everywhere upon a bed of limestone, familiarly known as "the short lime," but which may here be conveniently referred to as the *blanket limestone*. This bed varies in thickness from a few inches to about 2 feet. It is light gray, compact, and apparently nonfossiliferous. It effervesces freely with weak acid, and is an ordinary, slightly argillaceous limestone.

Below the limestone are usually found 5 or 6 feet of dark shales, alternating with very thin lenses of sandstone. Under these is generally a second bed of limestone similar to that above, and below this limestone come sandy shales and sandstones, the latter predominating with increasing depth.

The blanket resting upon the blanket limestone varies in thickness from 2 to 20 feet. The average is perhaps 6 feet. It is overlain by fissile, black shale which, so far as known, is never absent, and performs an important function in keeping out, by its imperviousness, the abundant surface waters. Above the shale are beds of sandstone and sandy shale, all more or less fractured and soft, which extend up to the loose surficial material covering the hill. The only workings in these upper beds are the vertical shafts sunk to the blanket below, and as these are necessarily closely timbered, and now mostly inaccessible, there is little opportunity of studying the beds which they penetrate.

The blanket itself dips with the inclosing beds, generally southerly, at about 15°, but it is warped and irregular (see Pl. XXXVII). For the entire thickness it is sometimes made up of a mass of small shale fragments embedded in a matrix of still more finely comminuted shale particles. This breccia passes upward, with no sharp break, into less disturbed shale, which in its turn grades into the so-called "shale roof." Occasionally fragments of soft sandstone are mingled with the shale flakes in the breccia. When this is the case, the rock immediately above the blanket is usually a bed of the same sandstone, the brecciation having involved the entire thickness of the shale. Seams of gouge show that there has been some movement within the breccia, due partly to faulting parallel with the bedding; but this motion has been local, and the blanket as a whole can not be regarded as a simple friction breccia due to a bedding fault. In structure and general appearance the blanket breccia is perfectly reproduced, artificially, when shale waste is dumped into an abandoned stope and allowed to slightly consolidate.

As a rule the breccia constitutes but the upper part of the blanket. The lower part, resting directly upon the blanket limestone, is commonly a soft, gray, silty material, frequently showing a laminated structure suggestive of water-laid origin. This deposit varies in thickness, and in its upper part is mingled with fragments of shale. Wherever ore occurs in the blanket, it is usually as a replacement of this material, which is evidently the "pulverulent lime" of Rickard.[1]

The foregoing description may be considered as applying to the typical and usual appearance of the blanket. But in some places considerable bodies of gypsum occur above the blanket limestone, occupying more or less of the space usually filled by the blanket. Such a mass occurs in the Enterprise mine south of the Group tunnel, and extends southeastward in the direction of the Vestal and Aspen shafts. It is perhaps continuous with the gypsum said to have been encountered near these shafts in the Rico-Aspen workings. Another large body occurs in the Rico-Aspen mine, near the Silver Glance shaft. The maximum thickness of the gypsum is not now revealed,

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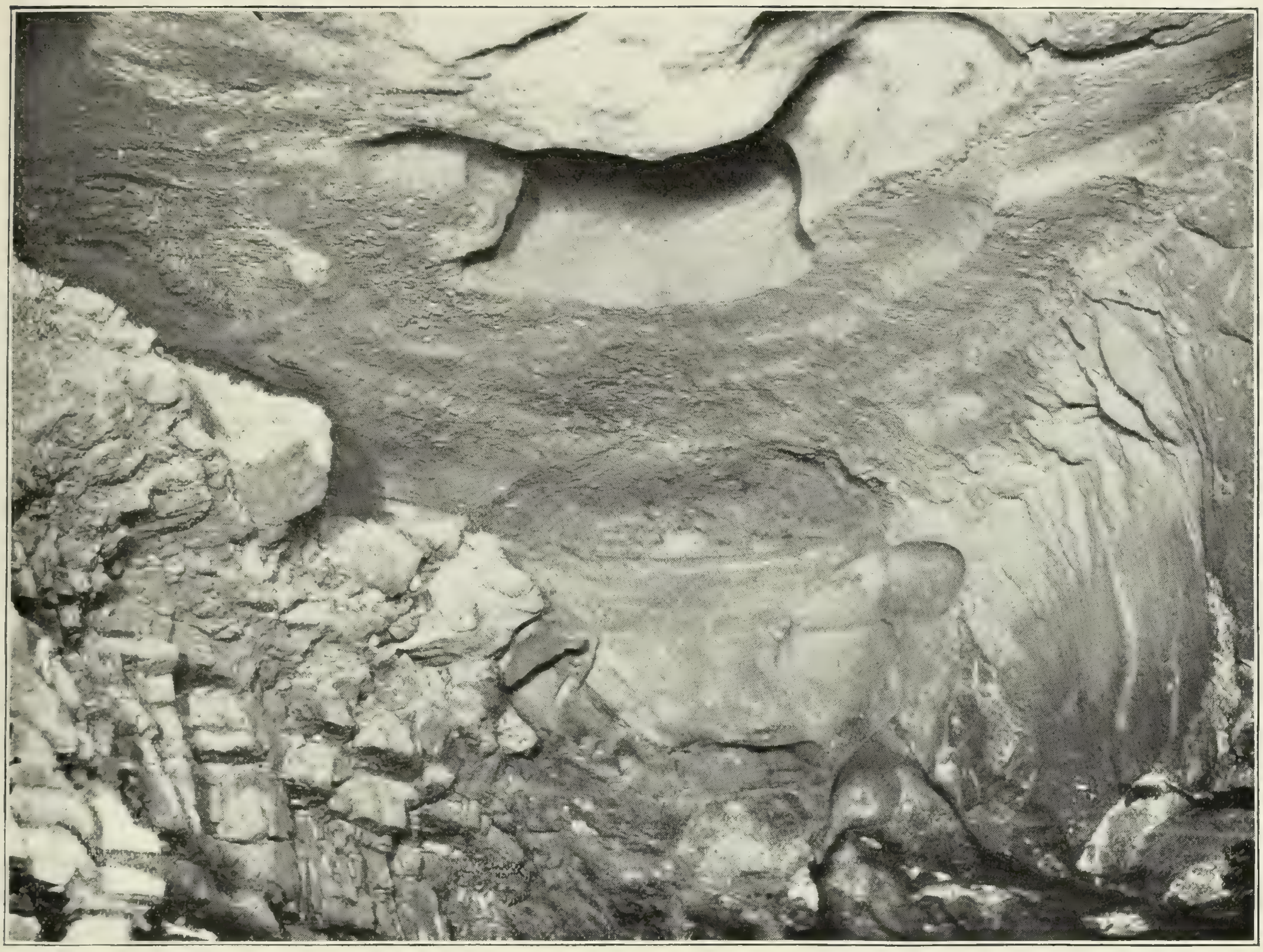
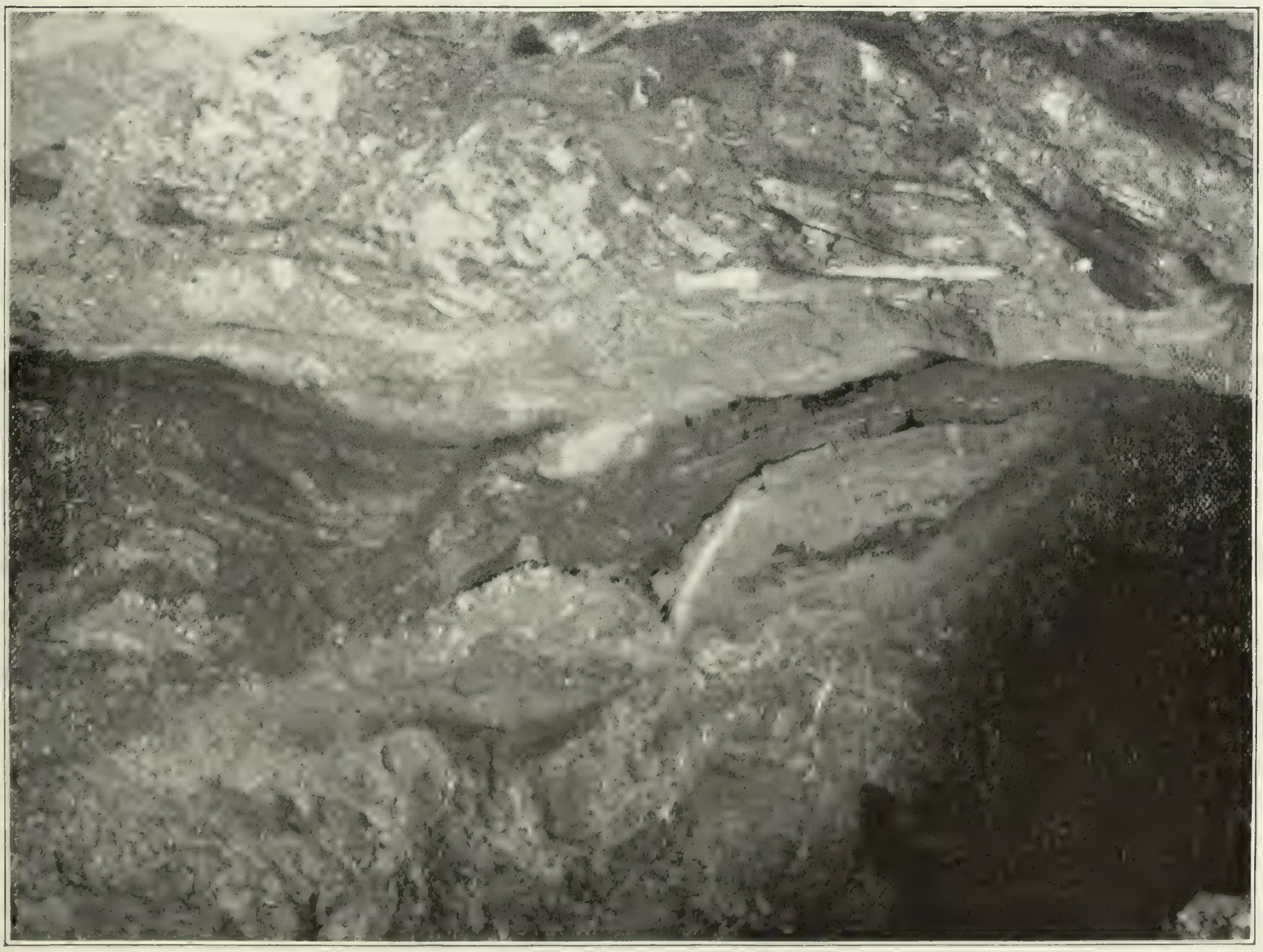
[1] Loc. cit., p. 968, and elsewhere.



A. UNDER SURFACE OF GYPSUM BED, SHOWING SOLUTION CAVITIES. RICO-ASPEN MINE.



B. BLANKET OF THE NEW YEAR OR GOLDEN FLEECE MINE.

Photograph by G. W. Tower.

but it probably exceeds 10 feet, and may reach 30 feet.[1] It sometimes rests directly upon the blanket limestone with an undisturbed contact of deposition, the latter so close that a knife blade can not be thrust into it. In other places the two rocks are separated by a varying thickness of the gray silty material already described as a characteristic constituent of the lower portion of the blanket. Wherever this occurs, however, the under side of the gypsum shows evident signs of solution. This is well shown in the Rico-Aspen mine, near the Silver Glance shaft, where the photographs were taken from which Pls. XXXII, *A*, and XXXIII were made. The gypsum is seen to be pitted with rounded, pothole-like cavities up to 8 feet in diameter. Lying upon the limestone under these cavities is always more or less of the gray silty material already noted. The general form of the cavities and the relation of the gypsum to the underlying and overlying beds is shown in fig. 56, p. 337, from a sketch near the Silver Glance shaft. It is reported on good authority that in the old Enterprise workings cavities or "water courses" in the gypsum large enough for a man to crawl through were of frequent occurrence.

There are but few places now accessible where the peripheries of the gypsum masses can be studied. One such point was reached in the Enterprise mine, and the relation of the gypsum to the typical blanket material is shown in fig. 42. The gypsum was found to have the irregular, cuspate forms characteristic of a homogeneous substance wasting away by solution. The unconsolidated blanket breccia fits snugly against the reentrant curves of the gypsum, much as loose morainic material might crowd against the melting front of a glacier. The gypsum is dissolving, and as fast as it dissolves the blanket breccia and the gray silt take its place.

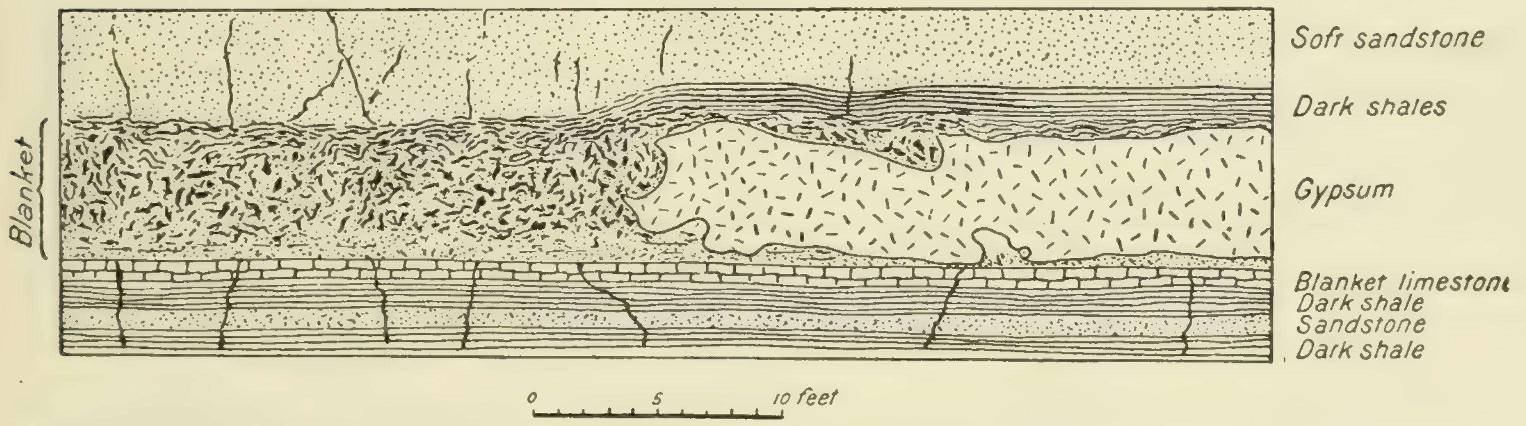


FIG. 42.—Diagrammatic section through a portion of the Enterprise blanket, showing relation of the gypsum to the blanket.

The gypsum, wherever seen, is massive, with an occasional suggestion of schistosity parallel to the general bedding. It is silvery gray on fresh fracture, fine granular in texture, and apparently nearly pure.

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[1] Rickard, loc. cit., p. 970, gives the maximum thickness, in the southwestern part of the Enterprise mine, as 15 feet.

A chemical analysis of a sample collected near the Silver Glance shaft is given in Column I of the following table:

Analyses of gypsum from Rico-Aspen mine.

[W. F. Hillebrand, analyst.]

Constituent.	I.	II.
CaO	32. 49	17. 18
MgO	[a] . 92	12. 48
SrO	. 10	19. 49
SO_3	45. 07	17. 22
CO_2	1. 54	26. 34
H_2O	19. 61	. 80
SiO_2	. 51	3. 50
TiO_2	Faint trace.	....
Al_2O_3	[b] . 03	[b] . 80
Fe_2O_3	. 09	1. 62
MnO	....	. 09
BaO	....	Faint trace.
Na_2O	Traces.	. 18
K_2O		. 24

[a] 0.21 per cent as silicate.

[b] With trace of TiO_2, and (in II) of P_2O_5.

No. I also contains a faint trace of some metal precipitable by H_2S.

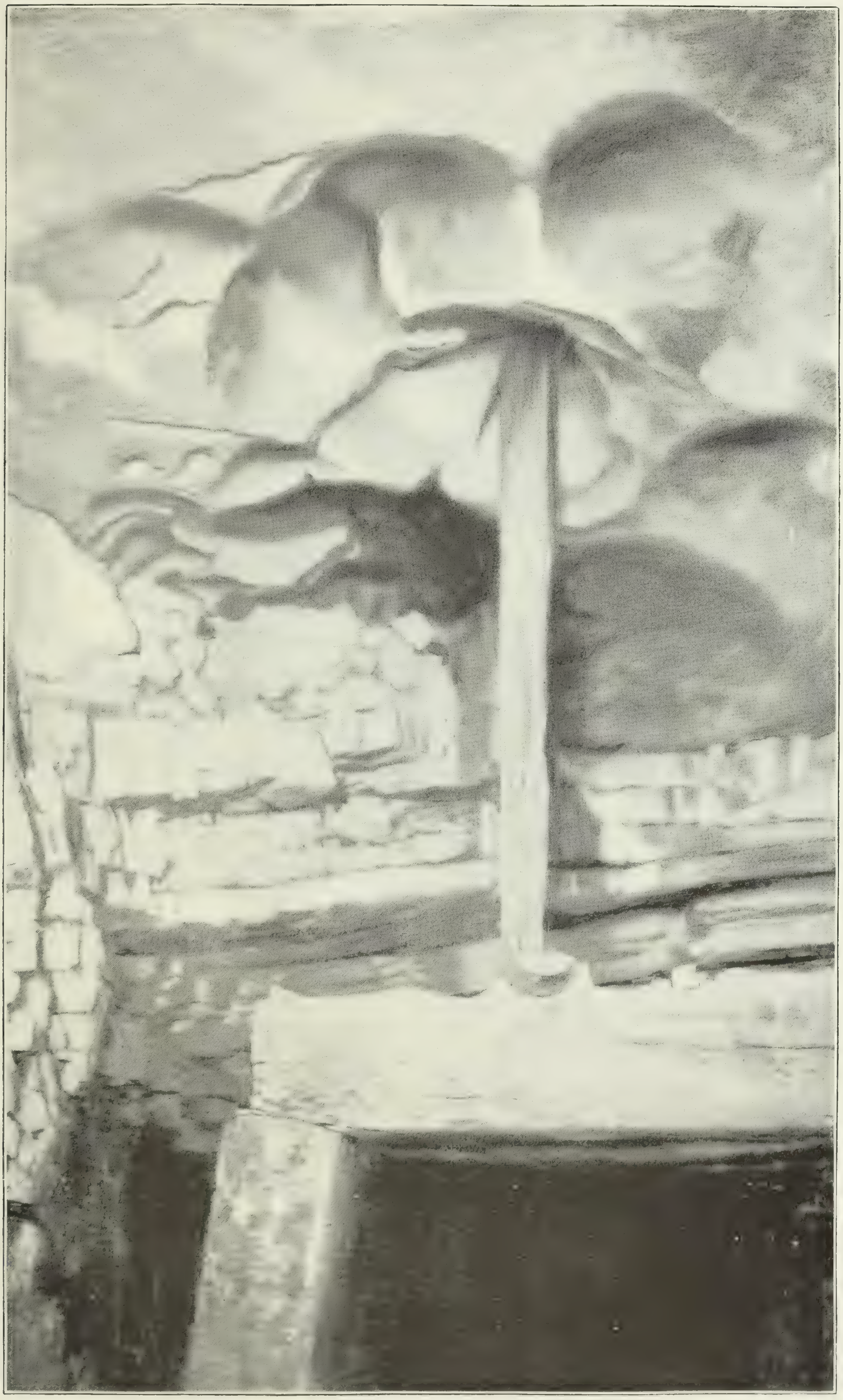
I. Gypsum, from near Silver Glance shaft, Rico-Aspen mine.

II. Alteration product, or residue, of gypsum, from same locality.

The analysis shows that the gypsum is of fair purity, but probably contains small quantities of dolomite, minute amounts of magnesium, iron, and aluminum silicates, and a very little strontianite or celestite.

In Column II of the table is given an analysis of the gray silty material so characteristic of the lower portion of the blanket, which has evidently been deposited as the gypsum was dissolved. The material chosen for analysis was collected near the Silver Glance shaft, at a point where it forms a layer about 1 foot thick, separating the gypsum above from the blanket limestone below. Samples were taken from the top and bottom of this layer, but they showed so little visible difference that only the lower one was analyzed.

When dry the material resembles a light-gray, dusty earth, sometimes faintly streaked with yellow, probably due to the presence of a little iron oxide. The clod-like lumps in which the substance dries may be easily pulverized between the fingers to a dusty powder, which reveals little or no grit when rubbed on glass. Under the microscope the powder is seen to consist chiefly of minute, colorless, crystalline



UNDER SURFACE OF GYPSUM BED, SHOWING SOLUTION CAVITIES.

grains, rounded in outline, but partly of prismatic habit. There is also an occasional grain of pyrite present.

The chemical analysis shows that this powder is essentially a mixture of dolomite and celestite, about 56 per cent of the former to about 37 per cent of the latter. The iron is probably present partly as pyrite and partly as limonite, or some other hydrous oxide. The alumina, alkalies, and water are very likely combined with the silica to form some unknown silicate or silicates present in minute quantity.

The mass relation between the original gypsum and the pulverulent material analyzed being unknown, it is impossible to closely calculate the gains and losses involved in the partial solution of the gypsum and the accumulation of this less soluble residue. A very large proportion of the original hydrous calcium sulphate, probably over 90 per cent, has been dissolved and carried away, and the analysis of the original gypsum can be compared with that of its residue only after the percentages of the latter analysis have been divided by some number to which it is possible to get but a very rough clew. If the alumina has remained constant during the change, then analysis II should be divided by 26.6. If the strontia has been neither increased nor diminished, then the divisor should be 194.9. These numbers are so different that it is unsafe to assume the constancy of either constituent, or even to employ the mean of the foregoing numbers as a rough approximation to the truth. It is possible that the material analyzed, coming from the bottom of the deposit, is richer in celestite than in the upper portion.

Although the chemical analyses do not suffice for quantitative calculations of losses and additions involved in the change, they bear out the unimpeachable testimony of geological occurrence that the gray, silty mixture of dolomite and celestite is essentially a residue from the solution of the gypsum. This residue, however, may have received some additional strontia from outside sources.

The occurrence of the gypsum in the blanket zone is a matter of more theoretical and practical moment than has hitherto been supposed, and it is important to gain some idea of the former extent of the gypsum and to understand its origin. It has been shown that the gypsum is in process of solution and that this solution is accompanied, step by step, by the accumulation of a silty residue of dolomite and celestite. The existing gypsum masses show characteristic solution forms on their peripheries. The blanket breccia, closely following up the process of ablation, crowds snugly against the wasting gypsum. The peculiar pulverulent mixture of dolomite and celestite, recognized as a product of the solution of the gypsum, is nearly always present in the lower portion of the blanket.

The foregoing facts not only prove that the gypsum once possessed a greater horizontal extent than at present, but they show beyond reasonable doubt that the gypsum was once coextensive with what is now known as the Enterprise "contact," or blanket. The recognition of the fact that the present gypsum masses are mere wasted remnants of a continuous bed that once occupied the entire space now filled by the Enterprise blanket is of more importance for an understanding of the genesis of the ore deposit than is the distinct question of the origin of the gypsum itself.

In the paper already quoted Rickard[1] refers casually to the gypsum and suggests that it has been formed "by a sulphatization of lime breccia through the agency of solution coming from neighboring ore-bearing measures." Spencer[2] has called attention to the fact that thick beds of gypsum occur in the corresponding portion of the Hermosa formation in the region of the Animas River, and has suggested that the gypsum of Newman Hill is in reality an integral part of the formation and not a secondary deposit. He has also suggested the possibility of the gray silty material, which he somewhat inaccurately terms "marl," being a residue left after the solution of the gypsum—a hypothesis which has just been shown to be well founded. That his view of the gypsum is in the main correct admits of no doubt. The fact that beds of gypsum are known to occur in the Hermosa formation a few miles away is alone strong presumptive evidence that the Newman Hill gypsum is an original member of the formation and dates from Carboniferous times. Wherever its under side is not pitted by corrosion it rests snugly upon the blanket limestone as a sharply distinct bed.[3] The formation of gypsum from limestone by the action of sulphate solutions is a process chemically possible, and one which is actually in progress in C. H. C. Hill. But the gypsum so formed is merely a dull, earthy crust on the limestone, is evidently dissolved nearly as fast as it is formed, and attains no considerable mass. The massive crystalline character of the Newman Hill gypsum and its purity render unlikely the hypothesis of its derivation from a sulphatized argillaceous and siliceous limestone. Such a hypothesis is made yet more improbable by the fact that the gypsum is now wasting away at a rate which would never have allowed it to accumulate in the first place through the chemical process suggested. Lastly, it is inconceivable that a mass of limestone from 10 to 30 feet in thickness should have been completely altered to gypsum, while the blanket limestone immediately below it shows no trace of such action. No such massive bed of limestone as is required by this hypothesis is known elsewhere in the beds of the Lower Hermosa, and the idea of metasomatic origin may safely be dismissed as a gratuitous

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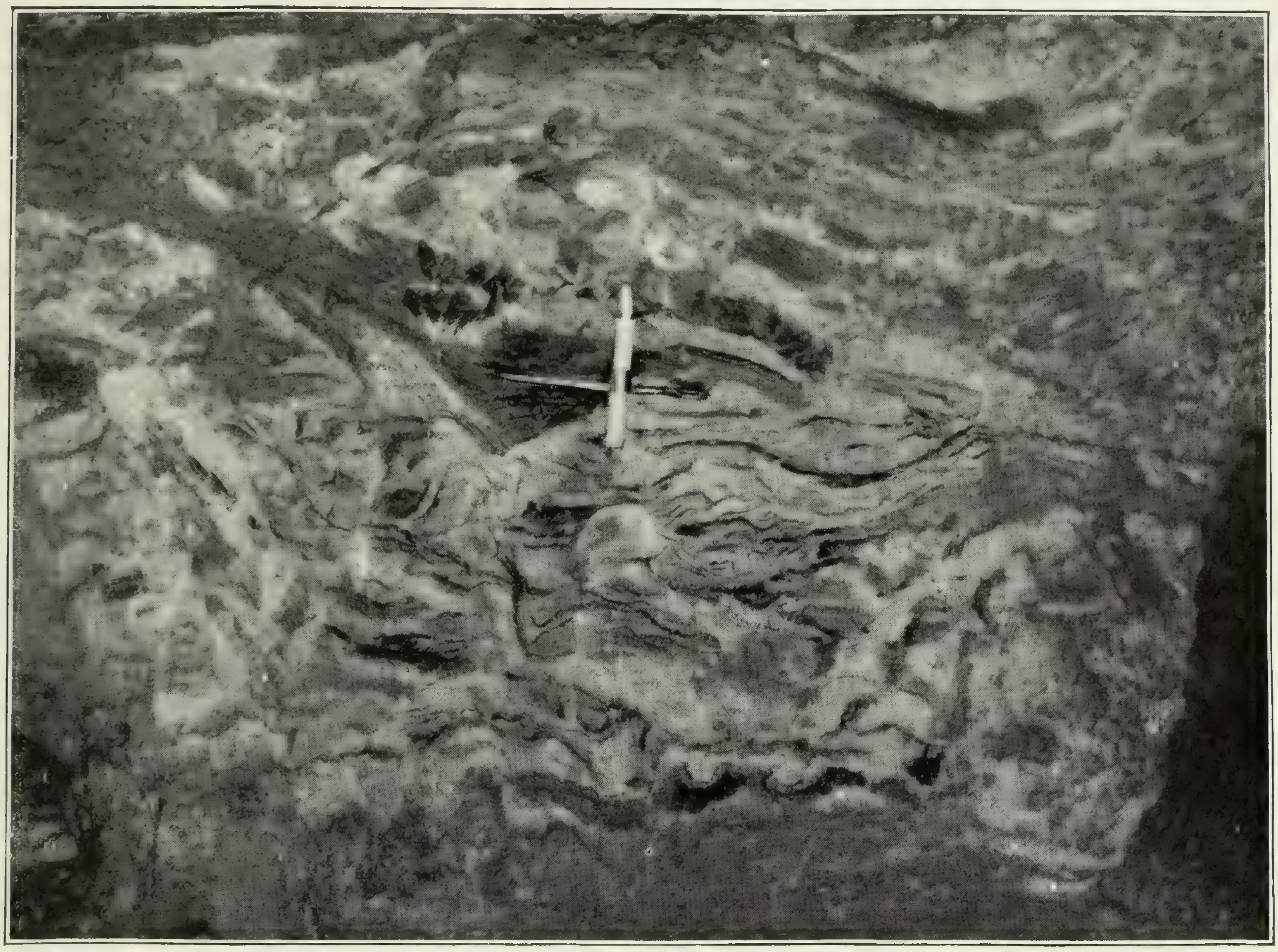
[1] Loc. cit., p. 970.

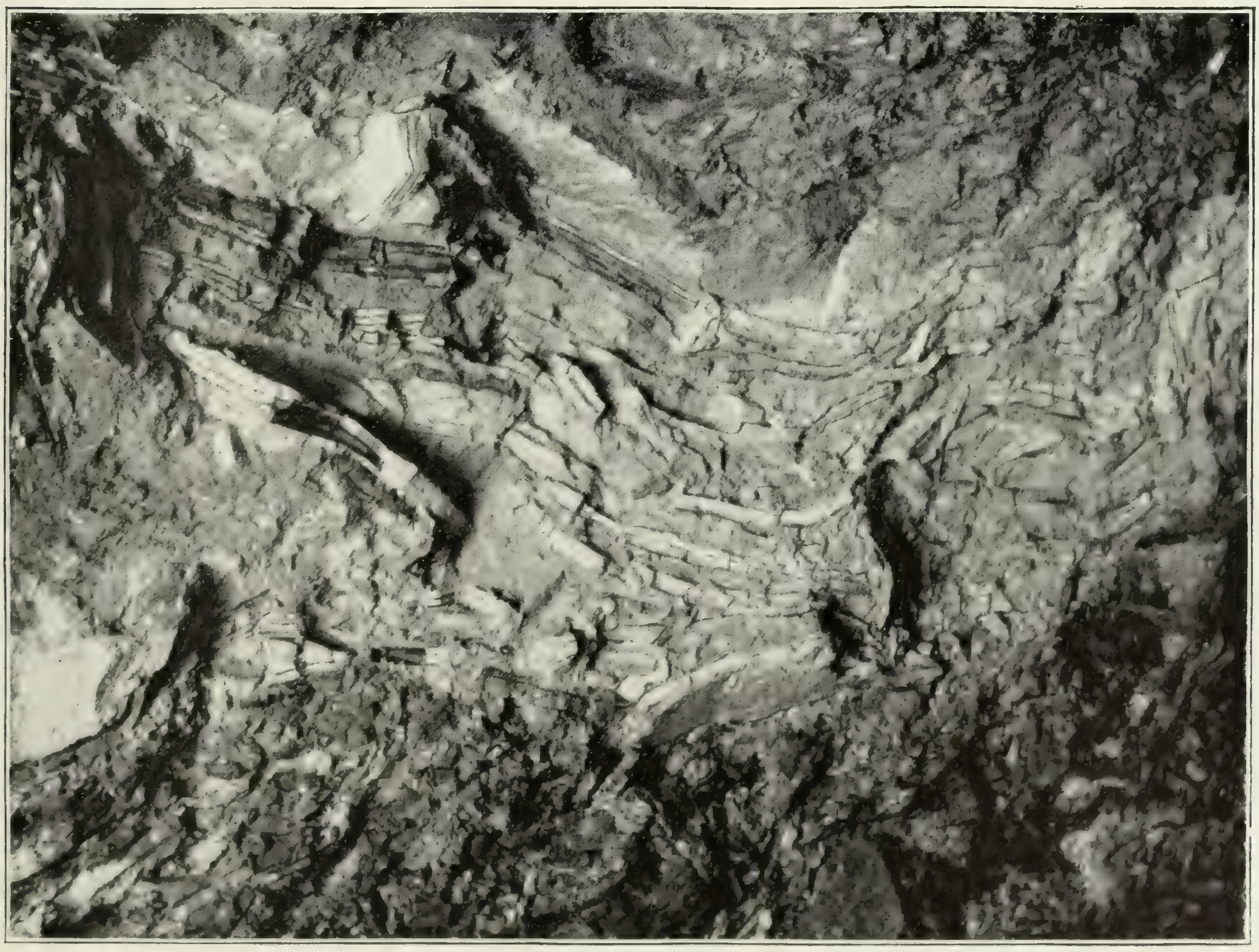
[2] Cross and Spencer, loc. cit., pp. 53 and 111.

[3] The statement of Spencer (loc. cit., p. 111) that the gypsum, "wherever it occurs, rests above the pulverulent limestone of the 'contact,'" is true only where more or less solution has taken place.



A. SILICIFIED SHALE BRECCIA IN THE ENTERPRISE BLANKET, ABOVE THE JUMBO NO. 3 VEIN.

Photograph by G. W. Tower.



B. UNMINERALIZED PORTION OF THE MAIN BLANKET, UNION-CARBONATE MINE.

Photograph by G. W. Tower.

suggestion. The Newman Hill gypsum was originally a bed laid down with the Hermosa shales, sandstones, and limestones. There are strong reasons for supposing that it was lenticular in form and may not have extended far beyond the present bounds of Newman Hill.

The blanket as thus far described, consisting of shale breccia and of pulverulent dolomite and celestite, has been locally modified through processes connected with ore deposition. The results of these processes may be classed as (1) silicification and (2) deposition of ore. Both of these modifications are directly connected with the lode fissures, and occur where the latter meet the blanket. Although closely related, silicification and ore deposition appear to have been to some extent antagonistic or mutually exclusive processes. The silicification sometimes involves the whole thickness of the blanket and even part of the blanket limestone. It is well shown in the Enterprise mine, in the so-called Bridal Chamber (Pl. XXXIV, *A*), above the intersection of the Jumbo No. 3 vein with a large northwesterly lode, and in the Rico-Aspen mine above the intersection of the Montezuma vein with two northwesterly lodes. In both these places all of the finer material of the blanket has been replaced by pure white quartz. The larger fragments have also been silicified, but can still be recognized as dark patches in the quartz. An example of such silicified dark shale is shown in Pl. XXXV. In this case the shale was only partly brecciated prior to silicification, and the specimen still shows a rough banding parallel to the original stratification. A chamber freshly excavated in such material presents a striking and beautiful appearance. Under the microscope, in thin section, the former shale fragments, in spite of their retention of dark color, are found to be altered to a finely crystalline mosaic consisting almost wholly of quartz.

Workable ore is sometimes associated with such a silicified blanket, but more often as silicification becomes prominent the ore vanishes, or vice versa.

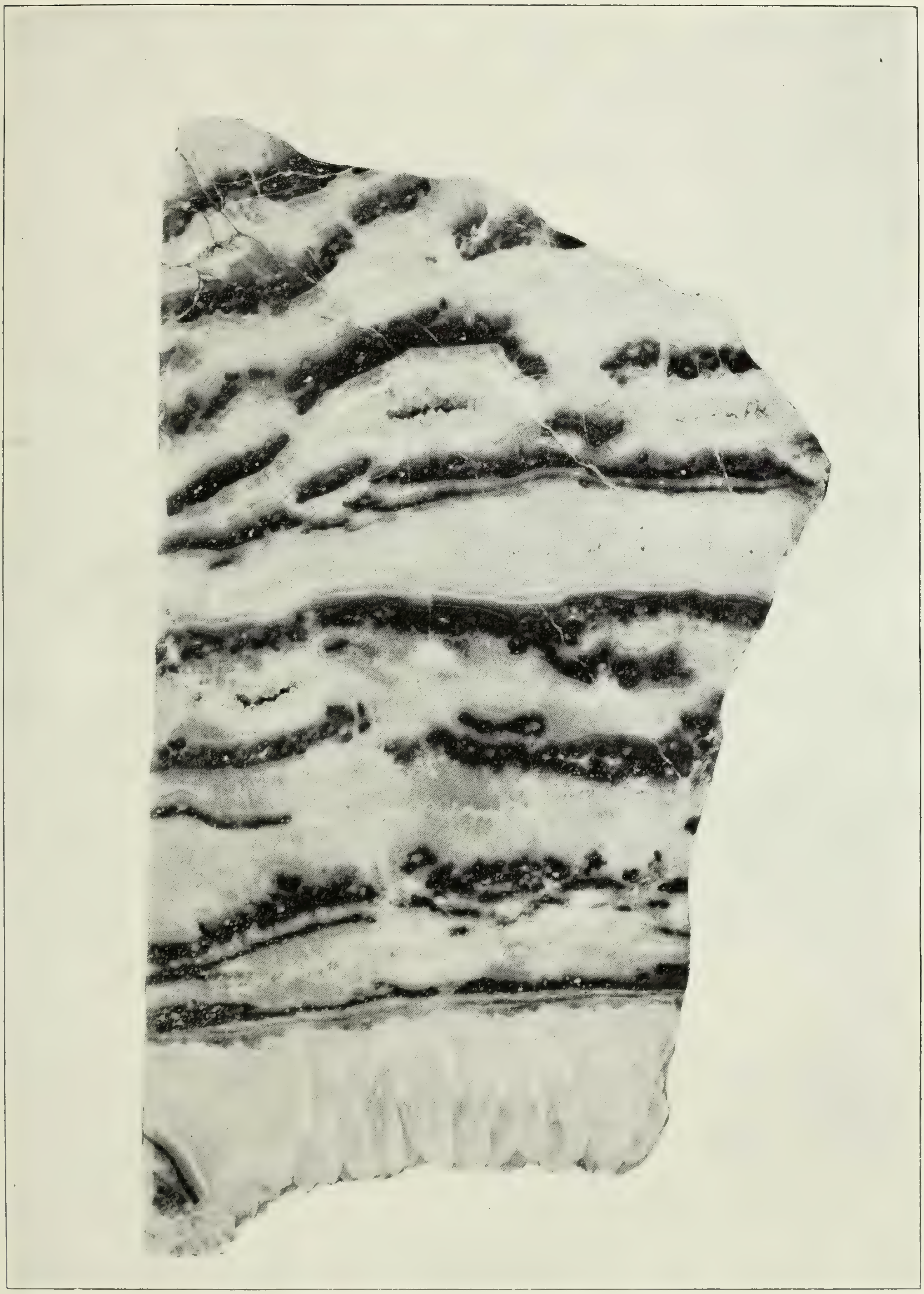
The blanket ore occurs chiefly as a replacement of the pulverulent lower part of the blanket above both the northeasterly and northwesterly lodes; but it sometimes extends up into the breccia, where it may perhaps have formed partly as the filling of interstitial spaces, as well as by replacement. It frequently partly replaces the blanket limestone, particularly where the latter is brecciated. No large bodies of "contact" ore could be seen at the time of visit, in 1900. In the southern part of the Rico-Aspen mine, above the Selenide vein, no ore is found where the gypsum occupies the usual place of the blanket, but it does occur farther north, where the gypsum has been dissolved away. In the vicinity of the Vestal shaft, however, and in portions of the Enterprise mine, ore is said to have occurred in the gypsum itself. A little of this ore was seen in the Enterprise in 1900. It occurs as irregular bunches in the lower part of the gypsum, having metasomatically replaced the latter. Such ore has a gangue of quartz, rhodochrosite, and selenite.

The usual blanket ore of the Enterprise and Rico-Aspen mines is similar to that of the northeasterly lodes, but presents certain differences which are always sufficient to identify it. It is usually less solid, and shows less regular banding, or none at all. Rhodochrosite is not so abundant as in the lode ore. The blanket ore consists of galena, sphalerite, and one or more rich silver-bearing minerals, in a quartz and rhodochrosite gangue which is often subordinate in amount. With the foregoing minerals are usually associated comparatively small amounts of chalcopyrite, and sometimes argentiferous tetrahedrite. Common pyrite is apparently very subordinate in the rich blanket ore. The rich silver-bearing minerals which have been identified include polybasite, in characteristic tabular crystals, argentite, proustite, and probably stephanite. Possibly other minerals also occur, but their exhaustive collection, isolation, and identification would constitute a special investigation.

Many other blankets occur in the Rico district, some ore bearing and some not. As a rule miners working claims on these blankets have a more or less confirmed belief that they are "on the Enterprise contact." Most of these "contacts," it is true, are in rocks belonging to the lower division of the Hermosa, and some of them may occur at the same stratigraphic horizon as the Enterprise blanket. But there entered into the formation of the latter certain conditions which increased its ore-bearing capacity and which appear to have been absent in the formation of all other blankets examined. The exact nature of these differences will be partly understood from the following descriptions and will be particularly dwelt upon in the section on the origin of the ore bodies.

A small blanket, of limited horizontal extent, is known in the Enterprise workings from 100 to 150 feet below the main "contact." It is a breccia of dark shale, which carried a little ore alongside of the Enterprise vein. The gray, silty material, characteristic of the main blanket, was not noted in this lower breccia zone, which, however, was seen only in the main tunnel.

New Year blanket.—Still lower in the stratigraphic series, and fully 400 feet below the main Enterprise blanket, is that of the New Year mine (Pl. XXXII, *B*). This is a strong zone of brecciated shales, resting upon an intrusive sheet of porphyry and overlain by soft shales. The blanket shows evidence of considerable differential movement between the overlying and underlying rocks. It is partly silicified and contains some low-grade ore. The monzonite-porphyry which underlies it is probably the same massive sheet encountered in the Skeptical shaft, at the bottom of the Jumbo shaft, and in the bore-hole driven below the Rico-Aspen workings.



SILICIFIED SHALE BRECCIA FROM THE ENTERPRISE BLANKET, NEWMAN HILL. NATURAL SIZE.

Cowdrey, Bancroft, Silver Swan, and Little Maggie blankets.—On the west side of the Dolores River, "contacts" occur in the N. A. Cowdrey, Bancroft, Little Maggie, and Silver Swan mines. These are all in Lower Hermosa rocks, but occur at various horizons. The N. A. Cowdrey blanket consists of two members of disturbed black shale, separated by a bed of limestone about 3 inches thick. The entire blanket is underlain and overlain by massive sandstone. Some low-grade ore occurs near the bottom of the lower shale at its intersection by a lode. The Bancroft blanket consists of soft shale breccia, mixed with clay, which rests upon massive sandstone and is overlain by shale. It is from 2 to 3 feet in thickness. In the Silver Swan mine a blanket consisting of about 6 inches of soft, gray clay or gouge passes upward into an unknown thickness of brecciated black shale. In the Little Maggie the principal blanket consists of dark shale breccia resting upon a bed of limestone and overlain by shale. It more closely resembles the Enterprise blanket than do the brecciated zones of the other mines, but none of the pulverulent mixture of dolomite and celestite was observed. This breccia contains small bunches of low-grade ore, but has been little explored. Several incipient or local "contact" breccias occur at various horizons in the dark shale of this mine.

Union-Carbonate blankets.—In the Union-Carbonate mine, on the north spur of Dolores Mountain, several blankets are known, none of which, in spite of their proximity and the fact that they occur in Lower Hermosa rocks, can be satisfactorily identified as the Enterprise blanket. The principal ore-bearing "contact" of this mine is composed of a zone of breccia resting upon a sheet of intrusive porphyry. It is sometimes overlain by porphyry and sometimes passes upward into relatively undisturbed shales. It has a thickness of 4 or 5 feet and in its less altered condition consists of somewhat mineralized fragments of shale and porphyry (Pl. XXXIV, *B*). The shale is often bleached nearly white and is partially replaced by ore, as described on pages 344–345 and illustrated in fig. 60, page 345. But where certain fissures intersect the blanket the latter, for a varying distance on each side of the line of intersection, is entirely replaced by masses of quartz and pyrite containing considerable bodies of low-grade ore.

Below the blanket just described occur several smaller and less important ones of different character. These are found in beds of dark shale, particularly in thin beds lying between relatively massive beds of sandstone or sheets of porphyry. When fully developed these blankets consist of a plastic yellow clay. The clay is an alteration product of the shale in place and often preserves traces of the original shaly lamination. Its yellow color is mainly due to hydrous oxide of iron, which readily dissolves in hydrochloric acid, leaving an apparently amorphous white residue the exact nature of which can be determined only by quantitative chemical analysis. It is not known whether this clay represents a direct alteration of the shale or whether it is due to the oxidation of some zone of alteration originally different in character. The alteration does not always involve the entire thickness of a bed of shale, but often constitutes a medial zone grading above and below into ordinary dark shale. The position and extent of this zone within the bed are probably dependent upon some variation in the composition of the latter. These clayey zones sometimes contain bunches of oxidized ore near intersecting vertical fissures.

Forest-Payroll blankets.—In the Forest-Payroll mine, about 1,000 feet northeast of the Union-Carbonate, there are two blankets from 30 to 50 feet apart, neither of which has as yet been identified with any of those of the Union-Carbonate mine, although, like the latter, they lie in strata belonging to the lower division of the Hermosa.

The lower blanket is about 5 feet in thickness. It is a breccia of shale, mingled with yellow clay, and resembles some of the blankets of the Union-Carbonate mine. It is underlain by sandstone and overlain by shale. The blanket is not a simple breccia throughout, but the softer, brecciated, clayey layers are sometimes separated by harder beds of shale or sandstone which have resisted the change undergone by the more susceptible beds and preserve in some measure their firmness and continuity. This blanket contains some rather low-grade ore where intersected and slightly faulted by nearly vertical northwesterly fissures. A little galena is found, but the ore is usually oxidized.

The upper blanket is 5 or 6 feet in thickness and rests sometimes on shaly, calcareous sandstone, sometimes on a sheet of porphyry. It is overlain by disturbed and broken shales. In its general appearance this blanket is similar to the lower one, but it contains irregular masses of limestone which bear much the same relation to the blanket that the gypsum bears to the Enterprise "contact." In some places the limestone occupies the entire thickness of the blanket, extending from the porphyry or sandstone floor up to the shale roof. It is often traversed by irregular fissures, filled with a black, sooty material, which is also very abundant throughout the blanket and is very like the product from the Nellie Bly vein, of which a description and an analysis are given on page 267. In other places the limestone is entirely absent, or occurs in isolated masses of exceedingly irregular form which are always covered with the black substance described and are embedded in the soft material of the blanket. The limestone, light buff in color and evidently impure, is finely granular in texture and is minutely banded or laminated parallel to the general bedding of the inclosing sediments. The sooty material is evidently an alteration product of the limestone. It penetrates the latter irregularly and works inward along the laminæ from the surfaces exposed to attack.

Chemical analyses of the limestone and of the sooty powder are given in the following table:

Analysis of limestone and its alteration product.

[W. F. Hillebrand, analyst.]

Constituent.	I.	II.	III.
CaO	39. 15	1. 06	2. 58
MgO	2. 29	14. 21	. 97
CO_2	[a] 30. 86	. 17	
H_2O at 110° C	. 51	7. 33	22. 81
H_2O above 110° C	. 66	[a] 8. 88	
SiO_2	23. 51	29. 29	15. 25
TiO_2	. 06	. 27	
ZrO_2	None.		
Al_2O_3	[b] 1. 56	12. 56	[b] 5. 73
Fe_2O_3	. 30	[d] 5. 36	13. 42
FeO	[c] . 56		
MnO	[e] . 54	MnO_2 13. 27	MnO_2 33. 77
ZnO	Faint tr. ?	1. 65	4. 75
CuO	Faint tr. ?	. 40	[f] . 72
PbO_2		5. 21	
BaO	Faint tr.	Faint tr. ?	
SrO	None.		
Na_2O	(?)	. 20	
K_2O			
Li_2O		Strong tr.	
P_2O_5	Tr.	. 14	Tr.
SO_3		Tr.	
Total	100. 00	100. 00	100. 00

[a] By difference.

[b] Trace of P_2O_5.

[c] 0.16 as carbonate.

[d] As F_2O_3.

[e] As carbonate.

[f] With CO_2, alkalies, etc.

I. Limestone. Forest-Payroll mine.
II. Alteration product or residue of above.
III. Oxidized material of Nellie Bly vein.

From the analysis in Column I, it appears that the limestone consists of about 70 per cent of calcium carbonate, with 30 per cent of siliceous and other impurities. The analysis in Column II shows that the alteration has consisted in the almost complete removal of the calcium carbonate and a strong hydration of the remaining constituents. The resultant product appears to be very largely residual in character, although probably modified by subsequently introduced material. In the absence of knowledge as to the mass relationship, or concerning the constancy of any one or more constituents, before and after the alteration, no quantitative comparison of the analyses is possible. The analysis in Column III is introduced for the sake of comparing the somewhat similar product resulting from the alteration of a calcitic vein.

The ore of the upper blanket consists mainly of galena in various stages of alteration to cerussite and anglesite. It occurs in small bodies at the intersection of the blanket by northwesterly fissures. It is not known to occur as a direct replacement of the limestone.

South Park blanket.—The South Park mine, at the northwest base of Newman Hill, was unfortunately not accessible in 1900. The ore is reported to have occurred partly in a blanket, in dark shales. If this is true, this blanket is the lowest known in Newman Hill, and occurs below the great sheet of monzonite-porphyry, while all the others lie above it.

C. H. C. blanket.—In C. H. C. Hill there is apparently one extensive blanket which has been exploited in the Princeton, C. H. C., Wellington, Logan, and Pigeon mines. All of the blanket thus far explored lies in a great landslide, and is consequently much broken and disturbed. This fact, coupled with the caving in of most of the old workings, makes it impossible to be quite sure that the principal blanket worked in the above-named mines is continuous and identical throughout. It certainly presents a more varied character, and is less open to simple explanation than those thus far described. It is thought to lie between beds of the upper division of the Hermosa, but this is by no means certain.

The blanket is usually 5 feet or less in thickness, and rests in some places upon sandstone, and in others upon limestone. It is overlain by sandstone or shale. It is most commonly composed of limonite, sometimes as a fairly firm, cavernous mass, but often as a loose, yellow, earthy material, which falls to powder between the fingers. In certain portions of the blanket the limonite passes into masses of crumbling iron pyrite, and it was undoubtedly formed by the oxidation of this mineral. The ore, when present, occurs in the lower part of the blanket, and is almost without exception completely oxidized. In the Princeton mine, the only place where any workable ore could be seen in 1900, it occurred in a soft, banded stratum, in which layers of an ocherous yellow powder containing a considerable proportion of silver, alternated with bands of impure pulverulent sulphate of lead, and streaks of a white material which proved on chemical analysis to consist of about 83 per cent of silica, 5 per cent of water, and 9 per cent of lead sulphate. The silica is probably in the opaline form. A little partly oxidized galena was seen in the southeastern part of the Logan mine, but its occurrence is apparently rare.

The main blanket of C. H. C. Hill is associated with considerable alteration of the rocks between which it lies. These changes are perhaps best studied in the Logan mine. The limestone which usually underlies the blanket has been largely attacked and removed by chemical processes. As a result its upper surface is most uneven. The process of removal is still in progress and the limestone is usually separated from the overlying blanket by a crust, an inch or more in thickness, composed chiefly of earthy gypsum (fig. 71, p. 392). What was supposed in the mine to be a thicker portion of the same crust of alteration proved on chemical examination to be halloysite, an amorphous, hydrous silicate of alumina, as shown by the following analysis, in which no other constituents than those enumerated were looked for:

Analysis of halloysite from the Logan mine.

[W. F. Hillebrand, analyist.]

Constituent.	Per cent.
SiO_2	38.65
Al_2O_3	33.27
Fe_2O_3	.22
H_2O at 110° C	13.70
H_2O above 110° C	14.34
Total	100.18

The gypsum is evidently formed directly from the limestone by the action of solutions containing iron sulphate, derived from the oxidation of pyrite. This is just the process that has been suggested to account for the massive bed of gypsum in Newman Hill. But whereas there are no extensive bodies of oxidized ore in the Newman Hill mines, the enormous bodies of oxidized and oxidizing pyrite in C. H. C. Hill have produced only a thin, earthy crust of gypsum, which is probably now dissolving as fast as it forms.

A chemical analysis of the limestone underlying the C. H. C. blanket in the Logan mine is given below. It is an ordinary compact gray limestone, not unlike the so-called "short lime" of Newman Hill. The sample for analysis was taken close to the gypsum crust, the line between altered and unaltered limestone being sharply defined.

Analysis of limestone from Logan mine.

[W. F. Hillebrand, analyst].

Constituent.	Per cent.
CaO	a55.10
CO_2	b43.39
SiO_2	.80
TiO_2	Trace.
Al_2O_3	.04
Fe_2O_3	.07
FeO	c.10
MnO	c.13
CuO	c.03
ZnO	c.09
MgO	c.25
BaO	None.
SrO	None.
H_2O at 110° C	Not det.
H_2O above 110° C	
P_2O_5+	A little.
S	dTrace.
Total	100.00

a 0.03 not carbonate.
b By difference.
c As carbonate.
d As pyrite.

The analysis shows that the limestone is notably pure, containing very little silica or alumina. It is of interest to find that it contains appreciable amounts of manganese, copper, and zinc. The formation of halloysite in the neighborhood of the limestone must, in the light of the foregoing analysis, require the addition of alumina and silica from outside sources.

The sandstone, unlike the limestone, is not directly soluble or convertible into soluble substances. Although in surface exposures it is greenish in color, throughout the C. H. C. Hill mines it is prevailingly nearly white. Under the microscope it is seen to be composed chiefly of quartz and sericite, the latter mineral being probably derived in great part from former fragments of feldspar. This sandstone is usually hard and firm, but within a distance of a few feet above or below the blanket it is decomposed to a soft, white mass, containing small scattered flakes of sericite mica, and apparently preserving much of the granular structure of the sandstone. Examined in powder under the microscope, this material is found to consist of a micaceous mineral in exceedingly minute scales, probably sericite, and numerous crystalline grains of peculiar form. These are short, stout spindles, with rough surfaces, such as might be produced by the corrosion of minute, doubly terminated crystals of quartz. These spindles are usually less than 0.1 mm. in length. Their optical behavior, so far as can be determined in such small bodies, is that of quartz, and their hardness is at least 7 of Moh's scale. None of the original clastic quartz grains were detected in the altered material. Analyses of the altered and comparatively unaltered sandstone are given in the following table. The samples were taken only a few inches apart, but the two facies grade into each other:

Analyses of sandstone and its alteration product from the Logan mine.

[W. F. Hillebrand, analyst.]

Constituent.	I.	II.
SiO_2	83.95	62.88
Al_2O_3	*a* 8.92	*a* 21.38
Fe_2O_3	.48	*b* 1.09
FeO	.13	
MnO	....	Very little.
Ag	.04	None or tr.
Pb	Tr.	.34
Cu	Tr.	....
MgO	.97	2.00
CaO	.12	.40
Na_2O	.06	.07
K_2O	3.09	6.59
H_2O at 110° C	*c* 1.90	*c* 5.49
H_2O above 110° C		
CO_2	None.	....
P_2O_5	None.	....
SO_3	....	.53
Total	99.66	100.77

a With some TiO_2. *b* As Fe_2O_3. *c* By ignition.

I. Sandstone.
II. Alteration product of above from same locality.

These two analyses, as they stand, constitute a comparison by unit weights. Such a comparison, however, is usually of little value in throwing light upon metasomatic changes, inasmuch as the latter nearly always involve change in specific gravity or in volume. Inspection of the analyses shows that if the percentages in Column II be divided by 2, the figures so obtained will indicate the preservation of a rough constancy in alumina, iron oxides, magnesia, lime, and potash throughout the alteration of the rock. This can hardly be a mere coincidence.

It at least indicates that the metamorphism has consisted chiefly in the removal of more than one-third of the silica of the original sandstone, the residual accumulation of the sericite, and diminution in volume. Partial mineralogical compositions may be very roughly calculated for the unaltered and altered sandstone as follows:

Sandstone.	Per cent.
Quartz	73
Sericite	24
Other minerals	3
Total	100

Alteration product.	Per cent.
Quartz	38
Sericite	56
Limonite, anglesite, and some hydrous magnesium mineral	6
Total	100

The occurrence of 0.04 per cent of silver in the apparently little altered sandstone is a wholly unexpected feature brought out by the analysis in Column I. This percentage is equivalent to 11.5 ounces per ton, and indicates that a large amount of silver is probably disseminated through the country rock of C. H. C. Hill in the neighborhood of the blankets.

The great extent to which oxidation has been active in the C. H. C. blanket renders the interpretation of the foregoing alterations difficult. Both the limestone and the sandstone show changes attributable to acid waters. The conditions for supplying surface waters with the necessary chemical activity are present wherever large bodies of pyrite are undergoing oxidation. It is very probable that the alterations just described are comparatively recent phenomena which have obscured whatever metamorphism accompanied the original deposition of the pyrite.

As might be expected from its position in a great landslide mass, the C. H. C. blanket, as well as the rocks which inclose it, shows much disturbance. Small step-faults, letting the blanket down by successive drops to the southwest, are said to have been very common in the old stopes, while irregular fracturing is everywhere conspicuous.

In addition to the main blanket of C. H. C. Hill, several blanket-like masses of pyrite occur at other horizons in the stratigraphic series. Three such bodies of crumbling pyrite, inclosed in shales, and aggregating over 50 feet in thickness, were passed through in the Crebec shaft before the main ore blanket was reached. Although nearer the surface than the latter, these pyritic bodies show almost no oxidation, and are too low in grade to be worked under present conditions. Similar, but smaller, bodies were noted in the Logan mine, extending into beds of shale on the southwest side of the Pigeon lode. In the Pigeon mine a small local blanket was found below the main "contact," and carried a little ore on the southwest side of a northwesterly fissure.

Some ocherous yellow, so-called "carbonate ore," collected from this blanket, proved on chemical examination to be composed mainly of the hydrous sulphate of iron and potassium, known as jarosite. A chemical analysis of this material is given below.

Analysis of impure jarosite from Pigeon mine.

[W. F. Hillebrand, analyst.]

Constituent.	Per cent.
SiO_2 (mostly quartz)	7. 35
Al_2O_3	1. 00
Fe_2O_3	43. 81
MgO	Trace.
CaO	. 06
Na_2O	. 08
K_2O	7. 44
H_2O	11. 64
P_2O_5	. 33
SO_3	28. 20
Total	99. 91

The particular sample analyzed can not be termed an ore. It was undoubtedly derived from the oxidation of iron pyrite, but is interesting as showing that considerable potash was probably present in some of the oxidizing solutions.

Still other relatively unimportant blankets, probably distinct from any of those described, are found in the Lily D. workings, on the lower slopes of C. H. C. Hill.

Taking them as a whole, the blankets of C. H. C. Hill present a striking contrast to that of the Enterprise mine. The constant shale breccia, passing below into the silty mixture of dolomite and celestite, which is so characteristic of the latter deposit, is absent in C. H. C. Hill, where the blankets appear to have been originally sheet-like or lenticular bodies, consisting chiefly of pyrite. The Enterprise "contact" is practically unoxidized, while the main blanket of C. H. C. Hill is almost wholly transformed to secondary products, and its earlier history thereby obscured. Without such oxidation and secondary enrichment, however, the ore would probably have been too poor to extract.

A. B. G. blanket.—On the west side of the Dolores River a small blanket occurs in the A. B. G., a prospect at Burns. This is composed of partly oxidized, crumbling pyrite, about a foot in thickness, lying between the beds of the Lower Hermosa, on the southwest side of the

A. B. G. lode. The pyrite is underlain by limestone and overlain by gray calcareous shale 3 or 4 feet in thickness, which in turn is overlain by shaly sandstone. The shale above the ore is often soft, and practically decomposed to a clay. Toward the northwest a bed of limestone comes in gradually between the ore and the overlying shales, and attains a thickness of 2 feet. Some movement between the ore and the overlying shales has evidently taken place since the ore was deposited.

Great Western blankets.—Two blankets are known in the Great Western prospect, on the north side of Horse Creek, in rocks that probably belong to the middle division of the Hermosa, and dip north at 15°. The upper "contact" is a soft, dark breccia of crushed shale, sandstone, and limestone, lying between two massive beds of limestone. In places this blanket is 6 feet in thickness and contains a sheet of monzonite-porphyry 3 feet thick, which has been altered to a soft, clayey mass containing much fine pyrite.

The lower blanket is about 6 inches thick, and consists of brecciated shale, lying between shaly limestone below and shaly sandstone above. It is apparently of no great horizontal extent, and neither of the blankets has produced much ore.

Sambo blanket.—The Sambo blanket, on the northeastern spur of Expectation Mountain, occupies a bedding fault, in Lower Hermosa rocks, between black shales below and gray, calcareous shales above. The zone of brecciation is replaced by quartz and ore on the southwest side of a northwesterly lode for a width of about 30 feet. Beyond this limit the silicification and mineralization die out and the breccia is practically unaltered. The quartz usually has a mottled appearance like that described in the Enterprise blanket and due to the same cause. Indeed, the Sambo "contact" is supposed by Cross and Spencer[1] to be a continuation of the Enterprise blanket. This, however, appears at best a doubtful correlation. The Sambo blanket has produced considerable rather low-grade ore.

Montezuma blanket.—Lastly, an unimportant blanket is known in the Montezuma mine, near Piedmont. This is an irregular "contact," consisting of crushed rock, gouge, and ore, resting partly on quartzite and partly on intrusive monzonite-porphyry. It is overlain by shales and sandstone. This is apparently a bedding fault along a bed of limestone which has been fractured and partly replaced by low-grade pyritic ore.

RELATIONS OF LODES AND BLANKETS.

As far as mining developments have shown, ore occurring in a blanket is always directly connected with some lode. The nature of the connection, however, is not always the same.

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[1] Loc. cit., p. 110.

In the Enterprise, Newman, and Rico-Aspen mines, in Newman Hill, the northeasterly and northwesterly lodes, as they approach the blanket from below, split up into innumerable small stringers, as is shown in fig. 43. These stringers are particularly numerous and noticeable in the blanket limestone and the shales that underlie it. They commonly consist of barren white quartz, although the stringers above some of the northeasterly veins contained rich ore. The aggregate result of these small fractures is to slightly fault the overlying blanket. In the case of the northwesterly lodes there is usually also a fault plane of more recent date, defined by a seam of gouge, which may pass upward through the blanket.

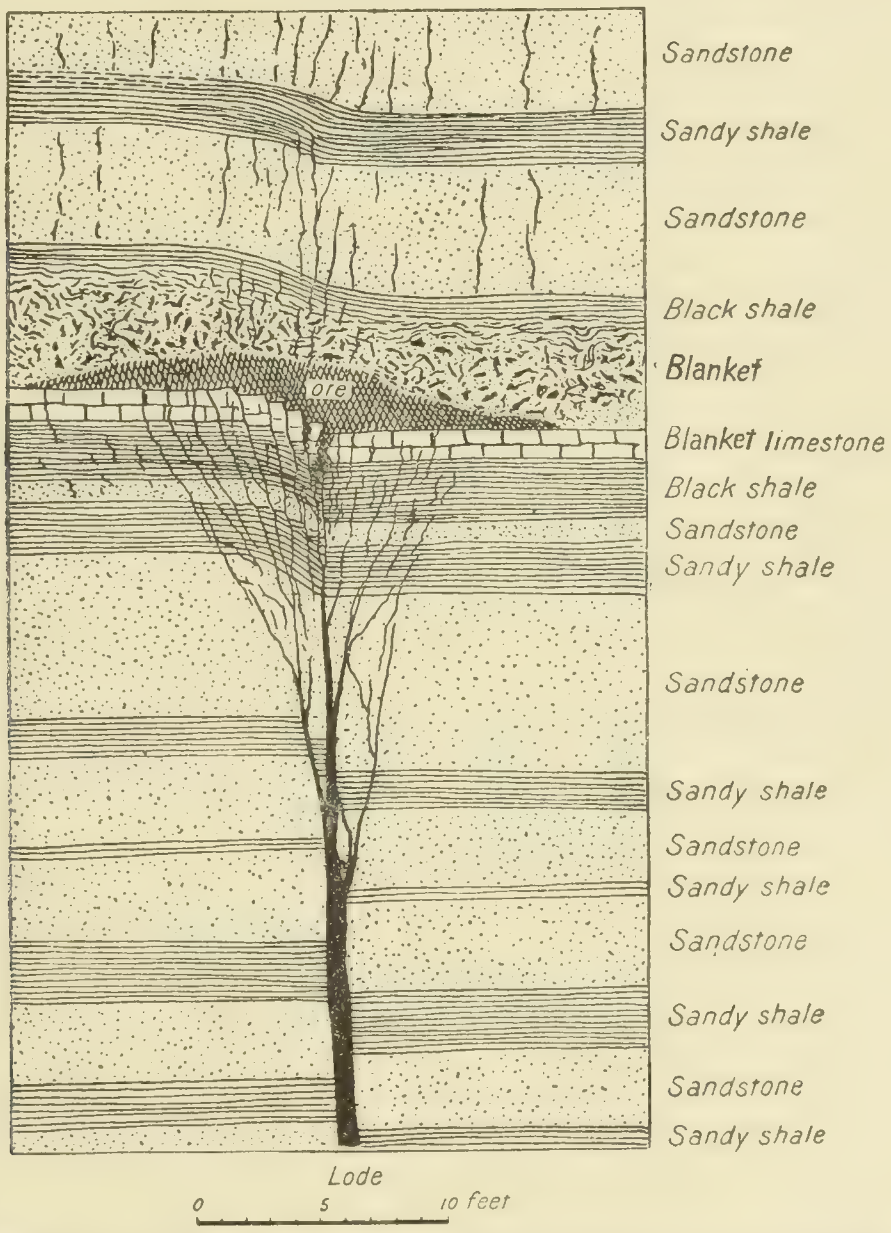

FIG. 43.—Diagrammatic section across a northeasterly lode and its blanket pay shoot.

In the blanket itself all of the lodes, as far as could be seen or learned, entirely disappeared. But their existence below is indicated within the blanket by the occurrence of the blanket ore, which caps them. These flat ribbons of ore, which followed the courses of the lodes beneath them, attained, according to Farish,[1] a maximum width of 40 feet and a maximum thickness of 3 feet, being usually larger over northwesterly than over northeasterly lodes. Above the intersections of two or more lodes the blanket ore body was often much more extensive. Farish[2] states that the blanket ore, while occurring directly over the northeasterly lodes, always "made" to one side of the northwesterly fissures, usually on the down-faulted side. The miners in general corroborate this statement, but there was no opportunity for confirming it at the time of visit.

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[1] Loc. cit., p. 158.

[2] Loc. cit., pp. 156 and 157.

With possibly one or two exceptions, which, however, are no longer open to examination, the lodes of Newman Hill do not extend above the blanket. The overlying rocks are much fractured and contain some unimportant veins, which may have been formed at the same time as the lodes beneath the blanket. But there is no good reason to suppose that they were ever continuous with the latter. The upward limitation of the lodes by the "contact" is a natural consequence of the slight faulting which accompanied the opening of their fissures and the yielding fissile character of the beds in which the "contact" lies. If the lodes continued in full strength up to the blanket and were there abruptly cut off it would be natural to suppose that they once extended to the surface and that their upper portions have been displaced by faulting. But not only do they practically die out, as lodes, before the blanket is reached, but the relations of the blanket ore to the lodes, of the blanket to the gypsum, and the nature of the blanket itself all support the view that the latter has not been a plane of extensive or general faulting.

In the Union-Carbonate and Forest-Payroll mines the blanket ore is connected with northwesterly fissures which apparently pass through the blankets without interruption. Whether or no the fissures are slightly faulted as they traverse the blankets could not be satisfactorily determined with the available exposures. The prevalent oxidation in these mines and the recent slipping along the lodes, as attested by the presence of gouge, tend to obscure the original relationship between lode and blanket.

In C. H. C. Hill the mineralization of the main blanket and of most of the smaller ones has plainly emanated from the great Pigeon–Blackhawk lode. Here, too, subsequent movement and oxidation have obscured the details of original connection. In this case the blanket is without much doubt considerably faulted by this lode, but it is impossible to say how much of the faulting took place before and how much after mineralization. All the ore so far extracted from the blankets of C. H. C. Hill has occurred on the southwest side of the Pigeon–Blackhawk lode. On the northeast side of the lode the blanket horizon was probably dropped by the original fault. But how far its position has since been changed by later movement, including landsliding, is not known.

The blanket ore of the C. V. G. mine at Burns is evidently connected with the northwesterly lode lying northeast of it, but the connection is not exposed.

In the Sambo mine the blanket is continuous with a lode which faults the Lower Hermosa beds to the extent of at least 4 feet. As shown in fig. 64, page 366, blanket and lode are directly connected. The ore occurs on the southwest side of the lode and extends into the blanket for a maximum distance of about 30 feet.

REPLACEMENTS IN LIMESTONE.

The principal examples of this form of ore deposition are found in the Blackhawk, Iron, and probably, also, the Puzzle mines. The Atlantic Cable and other prospects in the Ouray limestone north of Rico must also be placed in the same category.

In the Blackhawk the replacement ore bodies occur on the northeast side of a lode belonging to the Blackhawk fault zone. They have irregularly replaced a bed of massive limestone belonging near the top of the Middle Hermosa and dipping away from the lode to the northeast at an angle of about 25°. They attain a thickness of more than 15 feet and extend to a maximum distance of 50 or 60 feet from the lode. These bodies are composed in great part of massive pyrite of no present value, in which lie irregular bodies of workable ore. The best of this consists of fine-grained galena, chalcopyrite, and pyrite in a gangue of fluorite. Such ore grades toward its periphery into lower grade ore, large quantities of which are still standing in the mine. This is composed of massive compact sphalerite and galena, with a little chalcopyrite, and practically no gangue. This ore in turn passes into enormous masses of nearly pure worthless pyrite or is directly inclosed in limestone.

As a rule, there is no sharp boundary between limestone and ore. The latter sometimes penetrates the white granular limestone in small bunches, but more often the limestone next the ore is changed to jasperoid.

For a fuller characterization of this deposit the reader is referred to the detailed description of the Blackhawk mine, on pages 368 to 373. The deposit is an ordinary case of simple metasomatic replacement which has extended outward from a lode fissure.

Similar in character is the occurrence of the ore in the Iron mine. Here Middle Hermosa limestones are partly replaced by ore on both sides of a lode which does not noticeably fault the beds. In the Iron mine the workable ore extends less than 12 feet from the lode, except in some cases where replacement has worked out along minor fissures in the limestone. The ore is usually massive, consisting chiefly of pyrite and chalcopyrite, with more or less calcite and quartz as gangue. It is of low grade. The ore has replaced the limestone directly, with little or no formation of jasperoid.

The mode of occurrence of the ore in the Puzzle mine is at present not directly determinable. It appears, however, to have been an irregular replacement of limestone by a siliceous ore containing argentite or other rich silver minerals. The ore occurred in a landslide block, and it is not known in what manner the replacement was brought about—whether the solutions emanated directly from a lode, or whether they found access, by various channels, to a brecciated zone or bedding fault immediately above the limestone.

In the Atlantic Cable and neighboring prospects, the Ouray limestone has been most irregularly replaced by more or less isolated bunches of ore of various sizes. The deposition of this ore was closely connected with a metamorphism of the limestone giving rise to chlorite, epidote, garnet, and wollastonite, as described on page 395. The ore consists chiefly of sphalerite, chalcopyrite, and galena, associated with much specularite. It is not visibly connected with any parent lode or fissure.

STOCKS

The only examples of this form of deposit known in the Rico district are in the Johnny Bull and Gold Anchor mines, at the head of Horse Creek. These, however, are individually of small importance and are but poor representatives of a type which finds much better exemplification in the stocks of the Red Mountain district in the San Juan Mountains.

The Johnny Bull stock has a diameter of 10 or 15 feet, and a depth of about 120 feet. It was inclosed in fine-grained sandstone of the Dolores formation, which is here cut by several dikes and irregular intrusions of porphyry. The ore, consisting of enargite, pyrite, free gold, and probably other minerals, was deposited largely by replacement of the sandstone, which is silicified and impregnated with pyrite in the vicinity of the former ore body.

A similar smaller stock, consisting chiefly of pyrite, occurs at a ower level in the Gold Anchor mine, nearly under the Johnny Bull.

GENESIS OF THE ORE DEPOSITS.

If the preceding account of the ore deposits of the Rico district clearly and truthfully sketches their essential features, the statement that they are genetically connected with the present geological structure of the region requires no further demonstration. But it remains to investigate this general and fundamental connection more closely, in order to properly discriminate and distribute the various effects traceable to one common source—the geological revolution through which beds, once nearly horizontal, have been elevated into a fissured dome, and subsequently carved by erosion into the topographic forms known as the Rico Mountains.

The vertical extent of the original Rico uplift is estimated by Cross and Spencer[1] at about 4,500 feet. A minor part of the elevation, at least 800 feet, is connected with the intrusion of sheets of porphyry between the beds of the sedimentary series. But the major part of the uplift was subsequent to these intrusions, and was associated with profound faulting, showing "the action at this center of a powerful vertical upthrust which is not demonstrably connected with igneous intrusion."[2]

Fuller discussion of the origin of the uplift is deferred by these writers until the movements of the San Juan region as a whole shall have been further studied.

That the ore deposition is chiefly connected with the later phases of uplift is shown by the fact that the intrusive porphyries are themselves traversed by lodes, and are invariably mineralized when occurring in contact with ore bodies. But it is probable that some of the conditions favorable to the occurrence of ore bodies were initiated during, or even before, the earlier stages of the uplift. This is particularly true of the blankets, which Cross and Spencer have discussed to some extent under the heading of "Bedding faults;" that is, dislocations which follow planes of stratification. It will be well, first, to consider briefly the immediate causes which led to the formation of individual blankets, and, afterwards, to determine the relation of these direct and local manifestations of activity to the general geological history of the region.

ORIGIN OF THE BLANKETS.

Study of the Enterprise blanket has confirmed the general suggestion tentatively thrown out by Spencer, that it is due essentially to the removal by solution of a massive bed of gypsum which may have been from 15 to 30 feet in thickness. As the gypsum has not dissolved at an equal rate throughout, and has been largely attacked from below, with the consequent formation of caverns, the overlying beds must have subsided unevenly as the gypsum was removed, and were probably often let down abruptly by the enlargement and final collapse of caverns of solution in the under side of the bed. Nearly all stages of the process may yet be seen in the Newman Hill mines, from the usual "contact," with no remaining gypsum, to a thick bed of the latter, showing (at least on its under surface, which alone is visible) places where solution has not yet been active. This irregular subsidence, proceeding at different rates at different times, throughout the area now occupied by the blanket, is amply sufficient to account for the brecciation of the overlying shale and for the generally shattered character of the rock up to the base of the wash covering Newman

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[1] Loc. cit., p. 22.

[2] Cross and Spencer, loc. cit., p. 112.

Hill. Indeed, the results of this subsidence find partial expression in the present topographic form of Newman Hill.

That more or less movement has taken place in the mass of shale breccia precipitated upon the soft, pulverulent residue of the gypsum is well shown by the occurrence within it of irregular seams of gouge. Such movement is probably still in progress, but it is chiefly local in character, due to varying adjustments, under gravitative stress, within the plastic mass. It can not be ascertained that any general faulting has taken place along this soft and structurally weak zone. Such faulting, if it occurred, has certainly not been extensive, and its assumption is not necessary to account for the brecciation. The lack of general faulting along the zone of such apparent weakness is probably to be accounted for by the local character of the blanket, its warped form, and the occurrence of solid masses of undissolved gypsum, all of which would tend to prevent general slipping.

As the gypsum was deposited in Carboniferous time, its solution may have begun at an early date; but it was probably much accelerated, if not initiated, by the original doming of the rocks coincident with the intrusion of sheets of porphyry between the beds. The later fracturing, which was associated with the final stage of uplift, must have still further hastened the process of removal by allowing to underground waters, heated by the intruded masses of igneous rock, a more active circulation.

The upper blanket of the Forest-Payroll mine is somewhat analogous in origin to that of the Enterprise. It is due in great measure to the local solution of a bed of limestone, and the consequent letting down of the overlying shales. In this case the residue of the limestone is a sooty material containing much oxide of manganese. Owing to the prevalent oxidation in this mine, it is impossible to determine whether the ore was originally deposited in the limestone before its solution. Apparently it was not.

Of still different origin are certain of the lesser "contacts" studied in the Union-Carbonate mine. In these the process has been purely chemical. Certain beds of shale have been wholly or practically altered to a soft, ferruginous, clay-like mass containing some oxidized ore. The fact that some of these soft zones are cut by dikes or porphyry (intruded prior to the alteration) which have not been fractured or displaced shows that their formation is unconnected with faulting along planes of bedding.

The genesis of the main blanket of C. H. C. Hill is not perfectly clear, owing to later oxidation and disturbance. It was evidently originally a large body of low-grade pyrite which has undergone oxidation and a concentration of its valuable constituents. This pyrite apparently occurred in large part as a metasomatic replacement of shale, limestone, and sandstone. But whether this replacement was preceded by brecciation is not known.

There are, however, a number of blankets in the district, such as those found in the Sambo, Great Western, Bancroft, Silver Swan, Little Maggie, and New Year mines, and probably the main "contact" of the Union-Carbonate mine, which seem to owe their existence chiefly to bedding faults. It can not be positively affirmed, however, that all of the blankets named are purely fault breccias. It is quite possible that some of them may have been initiated by the solution of gypsum, as in Newman Hill, and the traces of such genesis have been obliterated by subsequent movement.

The stratigraphic conditions under which, in this region, such brecciation has taken place are fairly constant. The fissile black shales of the Lower Hermosa are the rocks usually involved, not only by reason of their intrinsic weakness, but on account of their present distribution with reference to the center of orographic movement. Such shales are particularly susceptible to brecciation near their contact with some more rigid member of the lithological series, such as a sheet of porphyry, or massive beds of sandstone or limestone. When the bed of shale is relatively thin, and is inclosed between the massive strata, it is often entirely reduced to breccia. That the actual relative movement of the stronger beds need not be very great to produce brecciation in the shales between them is well illustrated in the Rico-Aspen mine, near the Silver Glance shaft. Some of the shales below the blanket limestone, lying between thin beds of sandstone, are here locally folded and crumbled to the verge of brecciation, while the sandstone above and below them are undisturbed, and the crumpling itself has no great horizontal extent. Similar incipient "contacts" in various stages of development were noted in the Little Maggie and other mines, often having but small horizontal extent, and plainly formed by only slight movements along planes of bedding.

A part of the necessary movement probably took place at the time of the initial doming of the beds by laccolithic porphyry intrusions. But the greater part, and obviously that which produced brecciation along the contacts between porphyry and shale, must have been effected when the final elevation was given to the dome by upthrust and faulting, and the rocks accommodated themselves to their new positions by slips along the bedding planes.

ORIGIN OF THE LODE FISSURES.

It is to this general period of later orogenic movement that the present fissure systems of the region belong. Such earlier fractures as may have resulted from the first relatively gentle doming were probably superficial in character over the central region of the dome and have been largely removed by erosion. The more deep-seated fissures which presumably opened beneath the flanks of the uplift were in all likelihood filled with dikes at the period of laccolithic intrusion. It is to the later fractures, which traversed the solidified masses of monzonite-porphyry, and which served as channels through which ore-bearing solutions could penetrate to the blankets, that the ore deposits are really due.

That the fissuring did not all take place at one time is shown by the fact that many of the lodes, particularly northwesterly lodes, show evidence of repeated opening; that the northwesterly fissures of Newman Hill, although probably initiated at the same time as the northeasterly fissures, subsequently faulted the former in several instances; and that the fissures of the Phœnix and Iron veins are apparently younger than the Nellie Bly fault. In fact, it is only necessary to study such lodes as the Aztec or Calumet, or the northwesterly lodes of Newman Hill, to see that movement along existing nearly vertical planes of weakness has continued to a very recent date.

One of the striking generalizations afforded by the study of the district has been the lack of coincidence between those fault fissures of such extent as to appear as "structural faults" and the lode fissures. Cross and Spencer, in their remarkably successful elucidation of a most difficult field, have to some extent obscured this distinction, through their procedure, not unnatural in such a region, of identifying a fault required by their interpretation of the geological structure, with the nearest lode of like trend exposed on the ground. An unfortunate result of their terminology is an apparent confusion of the Nellie Bly fault with the Nellie Bly vein, and, in consequence, of the latter vein with the Aztec lode.[1] Less important is the supposed identity of the Last Chance fault with the Last Chance lode, inasmuch as lode and fault are in this case certainly very closely related. That some faulting has taken place along lodes, both before and after their filling, is of course undeniable. But the great fault fissures of the district, numerous as they are, apparently nowhere carry workable bodies of ore, and are certainly only to a minor extent coincident with veins. The northeasterly veins of Newman Hill, and less certainly the northwesterly veins of Nigger Baby Hill, show that the favorable channels for ore deposition were not the great fault fissures which gave the district its final structure, but were clean, open fractures of but slight tangential displacement. Such fissures show no clear evidence of horizontal compressive stress. They are, so far as faulting has taken place, in the main, normal faults. It is believed, although not entirely demonstrable, that they represent the relatively slight readjustments necessary to restore the rocks to gravitative equilibrium after the greater faults had determined the main structures of the region.

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[1] Cross and Spencer, loc. cit., p. 119.

PAY SHOOTS.

The superficial character thus far shown by the pay shoots is one of the most interesting phenomena of the Rico district, and vitally concerns the permanence of its mining industry. As pointed out in the preceding sections, only a relatively small number of the lodes have been themselves productive, and those to a comparatively slight depth. In the case of the Nigger Baby Hill, Little Maggie, and Alleghany veins, the most important falling off in value takes place at the passage of oxidized into unoxidized vein matter. These veins thus owe their workable portions to a process enrichment which is of common occurrence elsewhere, is wholly secondary, and is well understood in its general features. Below this zone of oxidation the veins have not been successfully worked, and it is not certainly known whether the value of the primary ore suffers a still further diminution with increasing depth. This, however, seems probable.

The rather abrupt falling off in value of the northeasterly veins of Newman Hill at a depth of less than 200 feet below the blanket is not so readily accounted for. It will be recalled that both the northeasterly and northwesterly lodes are capped by pay shoots in the Enterprise blanket, those over the northwesterly lodes being usually the larger and richer bodies. As far as can be determined, the blanket ore over the northeasterly veins did not differ mineralogically from that over the northwesterly lodes. Furthermore, at a depth below the blanket greater than 200 feet the contents of the two sets of lodes are mineralogically identical. It thus appears that the mineralogical difference between the northeasterly and northwesterly lodes, which is so striking a feature in certain of the mine workings, is not, after all, so great as might at first be supposed from a comparison confined to one level. The contrast is one brought about mainly by the difference in depth to which the ore extended in each case.

Various hypotheses have suggested themselves in explanation of this phenomenon. Difference in the country rock can not be appealed to, for both sets of lodes traverse the same beds. For the same reason, differences in pressure and temperature can scarcely have been important factors. If, however, the northwesterly lodes are in the main later than the northeasterly, it is inevitable, from what is known of its origin, that some change in the overlying blanket must have taken place in the interval. It is possible that this change may have been of a character to influence ore deposition.

It has been thought possible that at the time the northwesterly lodes were being formed the gypsum may have been only in small part dissolved. In such case the blanket ore may have been originally deposited chiefly as a replacement of gypsum, a process which is known to have operated in some portions of the blanket zone. The ore-bearing solutions, checked by the gypsum overlying the lodes, and not finding in the slow process of metasomatic replacement sufficient opportunity for the deposition of their metalliferous contents, may have encountered in the upper portions of the fissures conditions favorable to the deposition of ore. One such general condition of ore deposition is believed to be sluggishness of circulatory motion in the ore-bearing solutions.

If mineralization through northwesterly fissures was of later date, it is conceivable that the more complete removal of the gypsum may have given all of the ore an opportunity for deposition in the unconsolidated blanket material.

If the foregoing hypothesis is correct, some structural evidence for it might be expected in the ore of the northeasterly pay shoots of the blanket. Unfortunately, however, all of the known ore has been mined out.

It has been previously pointed out that some grounds exist for supposing that the northwesterly fissures, while initiated at substantially the same time as the northeasterly fissures, did not gape open until a later date, and that such opening was gradual and intermittent. This suggests, as a second hypothesis, that the blanket ore may have all been formed at the same time, before the full opening of the northwesterly fractures, and that the nonoccurrence of ore in the northwesterly fissures is due to their contracted openings at the time of ore deposition.

Of the two hypotheses advanced, the former is regarded as more probable. But it is admittedly not much more than a suggestion, of which no demonstration can be made under existing conditions. But whichever one is accepted requires to be supplemented by further considerations relating to the chemical causes of precipitation before it can be regarded as complete.

Rickard[1] has advanced the view that the precipitation of the ore was effected by the "graphite" in the shales. In spite of the experiments recorded by him, in which silver and gold were artificially precipitated from solution by fragments of this shale, such direct and simple precipitation has evidently not taken place in nature. The ore, as has been shown, is not particularly associated with the shales, either in the lodes or in the blanket. In the former it is more commonly found between walls of sandstone, and in the latter it occurs mainly as a replacement of the pulverulent residue of the gypsum.

The view that those ore bodies showing a marked decrease in valuable sulphides with depth, and passing finally into practically barren pyrite, are due to the action of both ascending and descending solutions has come to be widely accepted, largely through its forcible presentation by Van Hise.[1] The Newman Hill pay shoots appear to constitute striking examples of ore bodies due to the mingling of solutions. That the purely ascending solutions rising through the fissures of this region have normally deposited only low-grade pyritic ores is abundantly exemplified throughout the district. But such solutions ascending in the fissures under the Enterprise blanket not only found their upward progress barred by the impervious shales above, but entered a markedly porous, unconsolidated zone, traversed by laterally moving solutions which must then, as now, have carried considerable calcium sulphate in solution. Too little can be learned of the chemical nature of the fissure solutions to determine whether the calcium sulphate acted as the precipitant. But that the precipitation was due, at least in part, to mingling solutions and not entirely to metasomatic replacement within the blanket is indicated by the fact that the ores extend below the latter for over 100 feet in the northeasterly lodes. It is thus seen that the depth to which deposition of pay ore extended in the lodes may have been determined by the equilibrium between the ascending solutions in the lode fissures and the laterally descending solutions in the blanket. Evidently if the lode fissures were small, and filled with solutions moving upward under considerable head, all the ore would be deposited in the blanket.

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[1] Loc. cit., p. 977.

Turning now to the other known blankets in the district, we find that none of them have contained such large or rich pay shoots as the Enterprise blanket. With the exception of an oxidized lode in the Union-Carbonate mine, the fissures through which the mineralization of these blankets has taken place are barren, or contain only a little low-grade ore. It is evident that the conditions for ore deposition in the Enterprise blanket were unusually favorable, and were determined in varying degree by the following peculiarities, which are not found associated together in any other blanket known in the district: (1) The underlying blanket limestone; (2) the gypsum and its pulverulent residue; (3) the overlying, nearly impervious, bed of black shale; and (4) the upward termination of the lodes at the blanket horizon. But although no one of the other blankets possesses all these advantageous attributes, yet they illustrate the general fact that in this region, ignoring for the present replacement deposits in limestone, large bodies of workable sulphide ores occur only where the solutions in the lode fissures have had opportunity to mingle with laterally moving solutions in a blanket. The extent and richness of the deposit depend largely upon the number of favorable conditions enumerated above which are present in any one case.

A similar statement may be made with regard to replacement deposits in limestone. Lode fissures which ordinarily carry no pay ore are frequently connected with bodies of workable ore in limestone, as in the Blackhawk and Iron mines. In such cases the concentration, which has enabled solutions ordinarily capable of depositing only low-grade pyritic ore to form relatively rich sulphide masses, has been effected not so clearly by mingling of solutions as by the process, probably in large part selective, of metasomatic displacement.

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[1] Some principles controlling the deposition of ores: Trans. Am. Inst. Min. Eng., Vol. XXX, 1900, pp. 27-176.

SOURCE OF THE ORES.

The ores of the Rico district were extracted from the rocks by aqueous solutions and concentrated under the conditions already described. In this, as in many other regions, stratigraphic disturbance, igneous intrusion, and ore deposition have been genetically connected. The ore-bearing solutions undoubtedly owe much of their efficiency in gathering, transporting, and depositing the ore constituents to heat derived from igneous activity. That some of this heat still remains is indicated by the thermal character of the water issuing from the west base of Nigger Baby Hill. It is possible, although not clearly indicated, that pneumatolytic emanations (i. e., gaseous products given off at high temperature) from the cooling masses of intrusive monzonite-porphyry may have increased the chemical activity of the originally meteoric water. But the known porphyry masses had certainly solidified and probably lost much of their initial heat before the ores were deposited. Moreover, had pneumatolysis been an efficient factor in ore deposition, we should expect to find the ores unmistakably related, both in genesis and position, to the porphyry masses. No such close relationship is apparent, unless the exceptional ore bodies in the Atlantic Cable and neighboring claims may be considered as indicating it.

The actual chemical character of these solutions is not readily determinable. Their action upon the sedimentary rocks which usually form the walls of the fissures is, with a few exceptions, inconspicuous and often obscured by secondary alteration. The presence of abundant calcite in the lodes of Nigger Baby Hill and of rhodochrosite in the upper part of the northeasterly lodes of Newman Hill indicates that the solutions contained carbonates, possibly alkaline carbonates. But the strong silicification of porphyry alongside of the Mohawk and Marriage Stake fissures points rather to the action of acid waters. It is possible that the waters ascending in the lode fissures were acid in character, but were modified by mingling with descending waters, the change from acid waters depositing quartz and pyrite to carbonate waters depositing calcite and rhodochrosite corresponding in general to the deposition of pay ore.

Equally impossible of definite answer is the question of the particular rocks and the precise depth from which the ores were derived, but it is believed that all of the rocks, particularly from the top of the

Rico formation down, have contributed some metalliferous constituents to the ore bodies, not by the narrowly confined, academic process known as "lateral secretion," but by the concentration, in favorable localities, of materials widely drawn from the rocks of the disturbed region, and often reaching the point of their final deposition after a roundabout journey to depths far below any ever likely to be reached by mining operations.

That small amounts of the heavy metals are at present widely distributed in the rocks of the Rico region, even when the latter show no visible signs of mineralization subsequent to their deposition, is shown by several of the chemical analyses made for this report. Thus, the limestone from the Forest-Payroll mine affords faint traces of zinc and copper. Limestone from the Logan mine contains 0.03 per cent of copper oxide and 0.09 per cent of zinc oxide, while sandstone from the same mine yields traces of lead and copper and 0.04 per cent of silver. Even the massive gypsum from the Rico-Aspen mine shows a faint trace of some metal precipitated by hydrogen sulphide. All of the specimens analyzed, however, came from the vicinity of ore bodies, and the introduction of heavy metals in sufficient quantity to be recognized in an ordinary chemical analysis is probably connected with the formation of the neighboring ore bodies. There are, however, no known criteria for determining whether minute traces of heavy metals found in sedimentary rocks are original or have been subsequently introduced.

The formation of the ore of the Atlantic Cable and neighboring claims is evidently connected with intense contact metamorphism, as shown by the paragenesis of the ore minerals and their close association with garnet, wollastonite, vesuvianite, pyroxene, chlorite, and epidote. The cause of this metamorphism is not clear. It is probably traceable, however, to the intrusive mass of monzonite between Iron Draw and Aztec Gulch, or possibly to some igneous mass which has been removed by erosion.

GEOLOGICAL AGE OF THE ORE DEPOSITS.

The age of the ore deposits can not be determined from a study of the Rico district alone. They are plainly subsequent to the doming and faulting of the region, but no definite date is assigned to these structures by Cross and Spencer. A tentative conclusion, however, may be drawn from the similarity in character between the monzonite of the Rico district and that of the Telluride and Silverton regions. It may be assumed as probable that the monzonitic intrusions of the San Juan Mountains and Rico Mountains, only a few miles apart, are referable to the same general period of igneous activity. In the San Juan the monzonite stocks cut the Telluride conglomerate (Eocene?) and the overlying volcanic series. Their intrusion probably took place in late Tertiary time. This relation indicates that the ore deposits of Rico are roughly of the same age as those of the San Juan Mountains, probably late Tertiary and possibly extending into the Pleistocene.

VALUE OF THE ORES.

The great bulk of the ore produced in the Rico district has been shipped crude, or smelted in Rico without previous mechanical concentration. Consequently the ore handled has been of rather high grade. Ore worth about $20 a ton, such as was produced from the Union-Carbonate mine, is considered "low grade." The ore of the Enterprise and Rico-Aspen mines varied widely in value but was usually rich. Thus, during one year, the average of the Enterprise was 200 ounces of silver and 2 ounces of gold per ton. One carload from this mine (about 10 tons) was valued at $8,000. The general range, however, appears to have been gold, from 0.2 to 1 ounce; silver, from 100 to 200 ounces; lead, up to 10 per cent; and zinc up to 15 per cent. The ore from the Rico-Aspen and Newman mines has generally been of lower grade than that of the Enterprise.

Some of the oxidized ore from Nigger Baby Hill was rich in silver, but rarely carried over 0.2 ounce of gold per ton. In 1900 ore containing over 300 ounces of silver per ton was being shipped in occasional carloads. Ore from the Hope and Cross mine has sometimes yielded over 200 ounces of silver per ton in carload lots.

The ore of the Puzzle mine is reported to have been rich, but in general the replacement bodies in limestone, such as those of the Blackhawk and Iron mines, are of relatively low grade. That from the Blackhawk contained from 10 to 30 ounces and that from the Iron mine from 20 to 40 ounces of silver, with practically no gold.

An attempt was being made in 1900 to rework the dump of the Enterprise mine by concentration, but the mill erected for this purpose was not in successful operation at the time of visit.

CARBONIC ACID GAS.

Prospecting within the Rico district is often much hindered by the abundance of carbonic acid gas, which issues from nearly every fissure traversing the rocks in the central portion of the dome. It is particularly troublesome in shafts, which become entirely filled by it. It occurs in the Lexington, Mediterranean, and Syndicate tunnels to such an extent as to render them inaccessible unless artificially ventilated, and a stream of this heavy gas was noted issuing from a fissure in the Blackhawk mine. But it is in the immediate vicinity of Rico that the evolution of the gas is most abundant. On the west bank of the Dolores River, on the Riverside, Smuggler, and Shamrock claims, it issues in many places with a bubbling noise loud enough to attract the attention of the passer-by, and in such volume as to suffocate birds and small animals that venture too near, attracted by the water through which it escapes. About 300 feet upstream from the Piedmont bridge the water of the river is kept in a state of violent ebullition by the escape of gas, apparently from an east-west fissure. A similar copious discharge constantly agitates the water in the bottom of the so-called "gas shaft," a shallow prospect on the southwest slope of Nigger Baby Hill. As shown by bore-holes on the Atlantic Cable claim and in the Rico-Aspen mine, underground reservoirs of gas exist under considerable pressure. In fact there is scarcely an opening in the ground near Rico that does not fill up with gas, and not a stretch of the river between the mouths of Sulphur and Horse creeks where bubbles of carbon dioxide may not be seen rising through the water.

It is possible that the evolution of gas may be a final manifestation of volcanic activity, and that its source lies at great depth. This view is in harmony with the issue of thermal water near the base of Nigger Baby Hill and with the former solfataric action indicated by the alteration of the porphyry of Calico Peak.[1] But it is also probable that carbonic acid gas is being continually produced by chemical reactions at moderate depths, especially by the action of acid solutions on the limestone. Such a reaction is the transformation of limestone into gypsum through the agency of sulphate solutions, observed in C. H. C. Hill. It is also conceivable that replacement of limestone by sulphide ore is still going on, giving rise to carbon dioxide. But this is not very probable, as the known bodies of limestone have been found to extend to less than 200 feet in depth. Below them lies quartzite of supposed Devonian age, resting unconformably upon the Algonkian rocks.

LANDSLIDES.

For full descriptions of the extent and character of the landslides of the Rico district the reader is referred to the chapter on this subject by Mr. Cross[2] in the paper so frequently referred to in these pages. Mr. Cross believes that they were caused by earthquake shock.

They are of later date than the period of ore deposition, but have an important economic interest on account of the hindrance which they impose upon successful exploitation. This is well illustrated in the case of the Puzzle mine where a body of rich ore occurred in a landslide mass which has slipped down from Darling Ridge and buried the former channel of Horse Creek. All attempts to find the source of this block, and the continuation of the ore body, have failed. The difficulty of the problem is apparent upon referring to the geological map (Pl. XLI) where it is seen that the whole northern slope of

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[1] Cross and Spencer, loc. cit., p. 93.

[2] Loc. cit., pp. 129-151.

Darling Ridge is covered with landslide material. The depth of this material is often several hundred feet, and rock in place can be reached only by tunneling. There is no means of knowing how far the Puzzle mass has slid. Even if the original source of the block is found after tedious and expensive prospecting it is by no means certain that there will be any ore there.

Similar difficulty is encountered in the landslide of C. H. C. Hill, which, as shown by the various mine workings, has a maximum thickness of several hundred feet. In this case also all of the ore thus far found has been in landslide material, and the main ore horizon has never been found in rocks in place. Even if discovered it is by no means certain that it would contain workable ore.

Similar conditions of obscurity obtain over a considerable area north of Horse Creek and on the southeast spur of Expectation Mountain. Prospecting undertaken in these areas without some realization of the nature of the disturbance which they have undergone is almost inevitably doomed to disappointment.

FUTURE OF THE DISTRICT.

No attempt to forecast the future of the Rico Mountains as a mining district can be fully assured of success. The following views are, at best, deductions from phenomena only imperfectly understood, and perhaps susceptible of different interpretation by others. Suggestions advanced after a few months' study of the region are not infallible, and should in all cases be considered in the full light of local knowledge and experience before being blindly followed.

From the description and discussion of the ore bodies, it appears that in the future, even more than in the past, the blanket and replacement deposits will prove of more importance than the lodes. It seems very doubtful whether, under the conditions of working likely to prevail for many years, the lodes can be extensively and profitably worked. The finding of small amounts of gold ore from time to time in the northwestern portion of the district leaves open the possibility that workable gold-bearing lodes may yet be opened up in this part of the area. But the prospects of extensive future development in this direction are not regarded as particularly bright.

As to the blankets, it is hardly probable that, in future, ore bodies will be found which will equal in richness and size those formerly mined in the Enterprise blanket. But the extent of this blanket is as yet imperfectly known. Followed under Dolores Mountain, it was found to grow smaller and to contain no ore. This portion was not accessible in 1900, but before exploration in this direction is abandoned it should be carefully determined whether the blanket, as far as prospected, still contains the pulverulent residue which testifies to the former presence of gypsum. If it does, then it would appear that there is still a fair probability of bodies of ore occurring to the east of those hitherto worked. On the south the blanket is, without much doubt, cut off, and, as Cross and Spencer estimate, has been dropped about 250 feet. The chances of finding bodies of ore in this downthrown portion of the blanket can be decided only by a knowledge of the ore bodies lying immediately north of the fault. If these became impoverished before the fault was reached, the probabilities are that the blanket south of Deadwood Gulch is not heavily mineralized. The general indications, drawn from mine maps and other sources, point to such impoverishment. But according to other accounts rich ore was found in the blanket up to the line of the fault.

The occurrence of the New Year blanket shows that there is at least one "contact" below that of the Enterprise, and probably others exist beneath the porphyry. They are of different character, however, from the Enterprise blanket. It is probable that they contain ore at their intersection by the lodes of the Enterprise and neighboring mines, but it is likely to be of lower grade than that hitherto worked.

On C. H. C. Hill the blanket-ore has thus far been found only on the southwest side of the Blackhawk–Pigeon lode. It is probable that the corresponding beds on the northeast side of this fault-fissure are also mineralized. They may not be oxidized, however, and in this case would be of low grade.

Considering, finally, the replacement deposits in limestone, we find that they have been only partially explored. As pointed out on page 372, the Blackhawk mine has exploited only one of several beds likely to contain ore. The Devonian limestone north of Rico, and extending eastward under the Hermosa beds, has been only superficially prospected, and no attempt has been made to determine whether it has been extensively mineralized by the Smelter and South Park fault fissures.[1] It must be said, however, that the outlook for finding continuous bodies of high-grade ore in the Devonian limestone is not regarded as particularly encouraging.

It seems on the whole that the future of Rico is dependent more upon the possibility of working large bodies of low-grade pyritic ore than upon any other factor, to which should perhaps be added the utilization of the sphaleritic ores for the production of zinc. Abundant low-grade pyritic ore is known in C. H. C. Hill, along the Blackhawk fault zone, in the Iron mine, and elsewhere. Unless such ores can be successfully worked, Rico is hardly likely to experience any permanent revival of mining activity, although small bodies of high-grade ore may continue to be found for some time.

But it is desired again to emphasize the personal and fallible character of the foregoing conclusions. The reader is referred to the facts presented in other portions of this report. From them he may draw his own independent deductions.

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[1] See Cross and Spencer, loc. cit., pp. 120-123.

DETAILED DESCRIPTIONS OF INDIVIDUAL MINES.

MINES OF NEWMAN HILL AND DOLORES MOUNTAIN.

ENTERPRISE MINE.

Situation.—This, which has been the most productive mine in the district, is situated on Newman Hill, about half a mile southeast of Rico, and about 400 feet above the town. It is reached from Rico by a wagon road, and by a short spur from the Rio Grande Southern Railroad.

Literature and history.—The Enterprise mine has been described in great detail by John B. Farish[1] and T. A. Rickard,[2] each of whom had charge of the development of the mine at different times, and wrote with the advantage which such experience gave. Since their descriptions were published many of the workings have become inaccessible, and all of the large stopes in the so-called "contact" have been allowed to cave in. Consequently the present account of the mine is indebted to these observers for many facts which it is no longer possible to verify.

The following historical account of the discovery and development of the mine is extracted from Rickard's paper:[3]

> In the spring of 1881 David Swickhimer, Patrick Cain, and John Gault sunk a shaft 35 feet deep upon their Enterprise claim on Newman Hill. This work was undertaken not upon the evidence of ore, but in the expectation of cutting the continuation of the veins successfully worked in certain claims farther south, owned by the Swansea Gold and Silver Mining Company. Without entering into a detailed description of the geological structure of Newman Hill, it is necessary, in order to make the early story of discovery clear to the reader, to say that the true rock (sandstone and limestone) is overlain by drift, through which shafts must penetrate before reaching the ore-bearing formation. The veins do not reach the present surface, save in the face of the landslip where Harry Irving first detected them. The three owners above mentioned traded their claim to George S. Barlow for $300 worth of lumber. Barlow continued the sinking of the shaft to a depth of 146 feet. On an adjoining claim, named the Songbird, another miner, A. A. Waggener, sank a shaft to the depth of 203 feet. The latter penetrated through the drift into lime shale; but the Enterprise shaft did not at that time reach the true rock. Both shafts got into very wet ground. In the meantime the Swansea workings were reported to be impoverished and, finally, exhausted of ore. It was also said that the veins did not extend northward; but the real fact was that cross veins had faulted the ore-bearing veins in a manner to be rendered clear later on in this account. Newman Hill was discredited, and early in 1883 the Enterprise and Songbird shafts were abandoned.
>
> A year later Larned and Hackett resumed work in the Swansea levels, and by mere accident discovered that the veins had not come to an end, but were simply dislocated. They prosecuted development, proved the continuity of the ore, and made large shipments. Their success induced Waggener and Barlow to relocate their abandoned claims late in 1886. But neither of them had any capital, and they

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[1] On the ore deposits of Newman Hill, near Rico, Colo.: Proc. Colo. Sci. Soc., Vol. IV, 1892, pp. 151–164.

[2] The Enterprise mine, Rico, Colo.: Trans. Am. Inst. Min. Eng., Vol. XXVI, 1896, pp. 906–980.

[3] Loc. cit., pp. 909–912.

were unable to overcome the heavy flow of water. In December, 1886, David Swickhimer bought out Waggener's interest, acting on knowledge obtained while working in the Swansea mine, which had satisfied him that the veins must extend into the Enterprise and Songbird claims. In March, 1887, he recommenced the sinking of the Enterprise shaft. In May he acquired one-half of Barlow's interest. In July the windlass was replaced with a steam engine and a pump. All this time Larned and Hackett were driving rapidly northward, and threatened soon to reach the boundary separating their territory from that of Swickhimer and Barlow. Unless the two latter succeeded soon in finding a vein in place, so as to permit a valid location, the claims could be successfully disputed. They therefore hurried the sinking, and in spite of bad luck, floods of water, and a general lack of experience, they struck ore on the 6th of October at a depth of 262 feet. The first assay gave 2.1 ounces of gold and 519.4 ounces of silver per ton.

This ore was 1 foot thick, and formed part of a "flat lode." In the light of later developments this discovery is known to have been a piece of particular good fortune, for the maps of to-day prove that it was the edge of the biggest ore body ever found on Newman Hill, and that a shaft put down 20 feet farther east would have missed it. This was the first evidence of the existence of a flat ore deposit. Swickhimer thought at first that it was merely a roll in the Enterprise—an almost vertical vein. It was, however, soon proved by the workings to be a bedded formation, conformable to the inclosing country. The shaft was sunk 60 feet below this "contact," and a drift was run westward until the increased seepage of water in the following spring proved too much for the pump and caused work to be confined to the contact. In July the water diminished, drifting was resumed, and in August, at a distance of 118 feet southwest of the shaft, the Enterprise vein was at last intercepted. The ore was 20 inches thick and assayed 3.2 ounces of gold and 285.5 ounces of silver per ton.

In May, 1890, the Songbird and Enterprise mines, together with much adjoining property, were acquired by the Enterprise Mining Company.

According to Rickard the workings in 1896 had a total length of 8 miles, and had yielded ore of the gross value of $3,500,000. In June, 1900, the workings had attained an aggregate length of 27 miles, according to Superintendent Percy S. Rider, and the total output had risen to about $4,000,000. The large increase in the extent of the workings and the proportionally small increase of the output are significant. The known "contact" ore bodies had been worked out, and in 1900 active mining for the time being had practically ceased.

Country rock.—The country rock of the Enterprise mine consists of sandstones, shales, and limestones of the lower division of the Hermosa formation (Upper Carboniferous) as described by Cross and Spencer. The total thickness of this division, exclusive of the porphyry sills, is estimated by these writers at about 800 feet, the Enterprise ore bodies occurring nearly midway between the top and bottom beds. The strata, as exposed in the Enterprise workings, have a general strike from N. 60° E. to N. 75° E. and dip southeasterly at from 10° to 15°. Local irregularities, however, are not uncommon, and the beds frequently dip to the southwest, as in the Group tunnel near the Enterprise vein, or even to the northwest.

Several partial sections of these beds have been measured and described. A generalized columnar section is given by Farish[1] in his paper already cited, and two measured sections were published by Rickard,[1] from observations in raises 900 feet apart; while a third, observed in the vicinity of Jumbo No. 2 vein, near raise 13, and published by Cross and Spencer, is reproduced below:

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[1] Loc. cit., fig. 1.

Section near Jumbo No. 2 vein, Enterprise mine.

Top.	Ft.	In.
7. Shale, black, somewhat brecciated	3	0
6. "Contact," consisting of gray pulverulent marly material, sometimes structureless, and sometimes stratified, frequently impregnated with silica, and varying in thickness from 1 to 2 feet	1	10
5. Limestone, dark and impure, breaking with vertical fracture; locally known as "short lime"	1	5
4. Black, fissile shale with occasional lenses of gray sandstone in the upper part	5	0
3. Limestone, similar to the "short lime," but very black with gash veins of quartz	1	6
2. Shale, dark gray in color	1	6
1. Sandstone	8	0
Total	22	3

No particular agreement can be traced in the sequence of the beds in Rickard's two sections—a fact of which he makes rather too much in his later discussion, as will be subsequently pointed out. Perhaps partly on account of an obvious lack of precision in his use of lithological terms, neither of his sections shows any recognizable agreement with that of Cross and Spencer.

To secure a clear presentation of those features of stratigraphy which are essential to an understanding of the ore deposits, a single significant bed may be chosen as a local datum plane, and the strata above and below it briefly described.

The significant stratum selected is a bed of limestone, the familiar "short lime" of the Rico miners. Farish says of it:

> It is a grayish deposit, varying in thickness from 18 to 30 inches, and occupies throughout Newman Hill the same stratigraphical position with reference to the other beds. From its close relation to the ore deposits, this band is locally known as the "contact limestone." It is inclosed between two layers of argillaceous shale, which are, however, quite different in appearance. The overlying stratum is a soft, comminuted, drab-colored shale, varying in thickness from 6 to 20 feet. This layer forms an impervious shed to the surface waters circulating above it, thus leaving the mine workings below comparative dry. The underlying bed is a black, finely laminated shale, from 7 to 12 feet in thickness, which rests upon the series of alternating gray sandstones and drab and greenish shales.[2]

Rickard,[3] finding that his sections failed to show stratigraphical agreement, flatly denies the above-quoted statement of Farish as to the persistency of the "short lime" and its superior and inferior shales. In this he is in error. Whatever may be true of the sandstones, shales, and limestones above or below the significant stratum, the general description given by Farish is essentially true for that portion of Newman Hill in which lie the workings of the Enterprise, Newman, and Rico-Aspen mines. In fact, Rickard himself, on a subsequent page,[1] speaks of the "contact" as occupying and possessing a genetic relation to a definite stratigraphic horizon.

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[1] Loc. cit., pp. 914-915.

[2] Loc. cit., p. 154.

[3] Loc. cit., p. 914.

The "short lime" or "contact limestone" is a light-gray, compact, and apparently unfossiliferous limestone. It effervesces freely with cold acid, but is probably slightly magnesian. It is easily fractured by movements of the rocks, and is frequently traversed by veinlets of quartz. It is sometimes speckled with very minute crystals of pyrite. Its average thickness is perhaps somewhat less than indicated by Farish, as it sometimes thins out to 5 or 6 inches, although it never wholly disappears.

Below this limestone lie the shales referred to by Farish and recorded by Cross and Spencer in their section. They are intercalated with thin beds of sandstone, which may frequently be followed until they wedge out. Thus the proportion of shale to sandstone varies from point to point, although the shale was nowhere found to be entirely absent. Passing downward in the stratigraphic section the shales become less abundant or more arenaceous, and at a depth of 100 feet below the "short lime" fine-grained, greenish-gray sandstones prevail, in moderately thick beds, with a little sandy shale and an occasional band of limestone.

Immediately above the stratum of "short lime" occurs the so-called "contact," which will presently be more fully described. It varies in thickness from 2 or 3 feet up to 20 feet according to Farish, and passes with no very sharp line of demarcation into an overlying bed of black clay shale. As far as known, this shale is never absent, and experience has taught the miners to avoid cutting through it, as when once pierced it is not only exceedingly difficult to retain by timbering, but the opening gives access to abundant descending water, to which the shale in its intact condition presents an impervious barrier. Owing partly to this fact, there are at present no opportunities for studying the beds above the shale. They have been penetrated by several shafts, but these are invariably lined with timber. According to the accounts of various men who have worked at sinking these shafts, the beds above the dark shale are chiefly sandstones, and are so soft and broken as to be easily worked with pick and shovel. Mr. Cornelius Williams, for many years foreman of the Enterprise, stated that in these soft overlying beds the thin sandstones and limestones are all more or less shattered and displaced. In the few instances seen, where the top of the shales had been exposed, the overlying rock was a soft sandstone.

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[1] Loc. cit., p. 976.

Finally, the surface of Newman Hill is cloaked to varying depths up to about 300 feet by Pleistocene wash, which effectually conceals from view most of the Lower Hermosa rocks.

General character of ore bodies.—The ore of the Enterprise mine occurs in two forms—in almost vertical fissure veins, and in nearly horizontal masses in the so-called "contact," or blanket, immediately above the "short lime," which may be called for convenience of description, the *blanket limestone*. The latter ore masses are genetically connected, not only with the productive or "pay veins" but also with another set of lodes, locally known as "cross veins" and generally barren. Various names have been given to these two systems of lodes, most of them somewhat objectionable in that they involve certain assumptions, or lay stress on more or less artificial distinctions. In this report the "vertical pay veins" of Farish, "verticals" of Rickard, and "pay veins" in the local vernacular, will be referred to as the *northeasterly veins*, from the fact that their courses fall in the northeast and southwest quadrants of the compass, while the "cross veins" for a similar reason will be spoken of as the *northwesterly lodes* or *veins*.

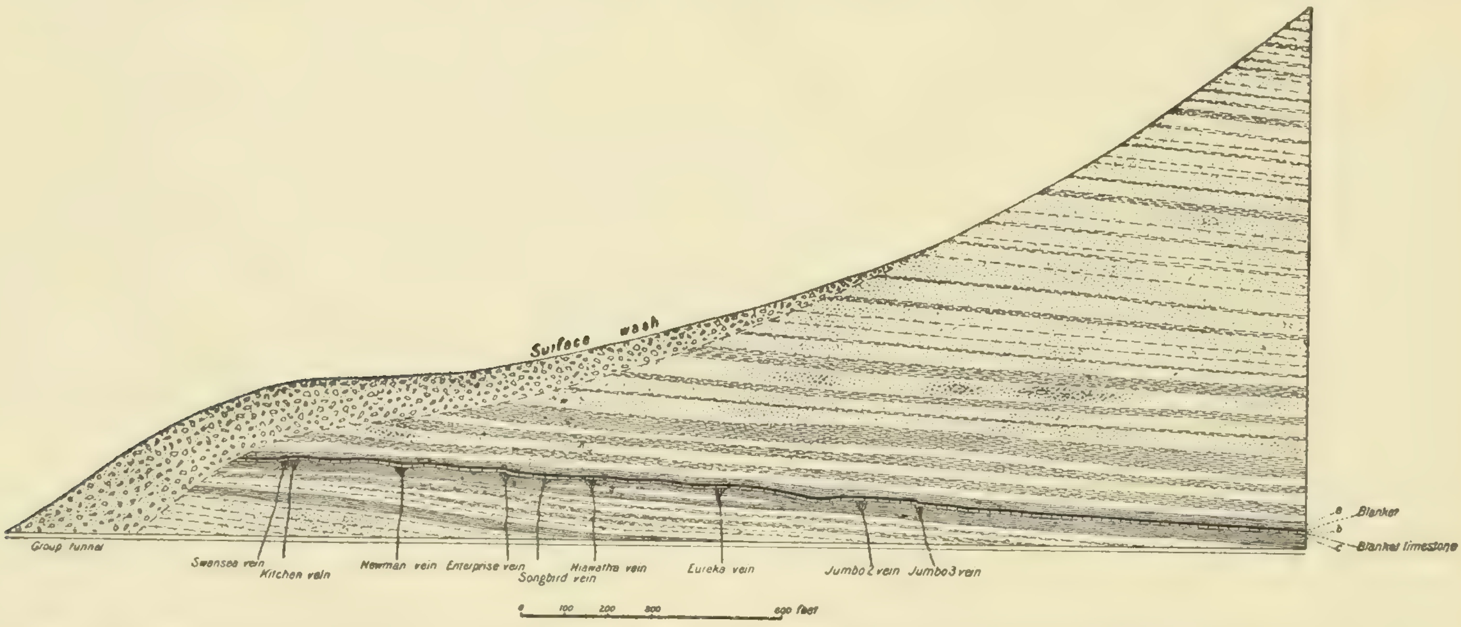
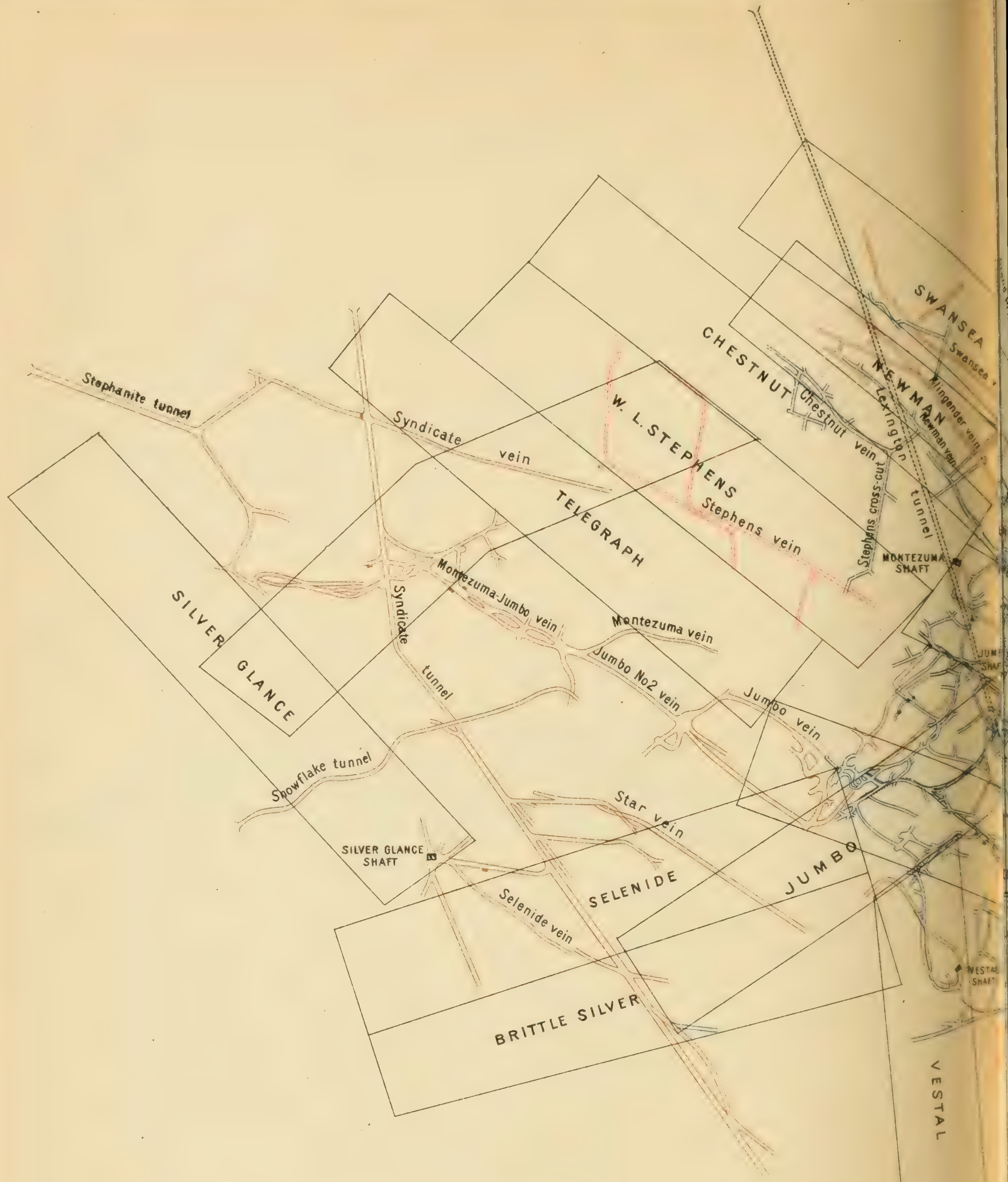


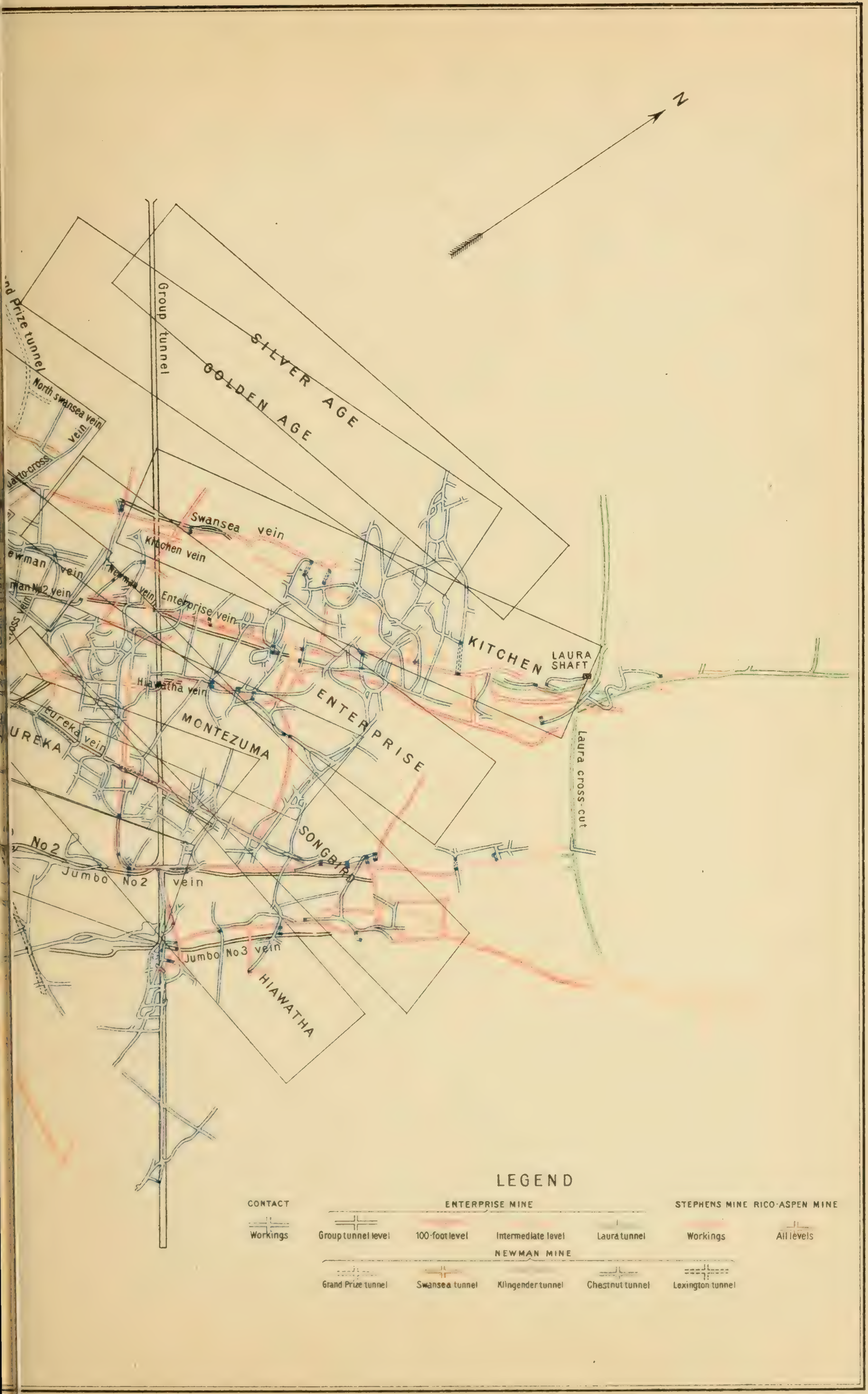
FIG. 44.—Diagramatic longitudinal section through the Group tunnel. Enterprise mine.

Development.—The mine is worked through a straight adit, known as the Group tunnel, about 3,000 feet in length, with a course S. 57° E. This tunnel lies wholly beneath the Enterprise limestone and consequently nowhere cuts the "contact." The latter is a little over 200 feet above the tunnel near its mouth, but is brought down by faulting, and by the general dip of the inclosing beds, to within 35 feet of the tunnel at its breast. The tunnel's course is such that the principal northeasterly veins are cut at nearly right angles. The general relation of the Group tunnel to the lodes and "contact" is illustrated in the accompanying section (fig. 44). As shown by the plan of the Enterprise workings (Pl. XXXVI) there are at least eight important northeasterly veins which have been worked for ore. These are, naming them in order from the tunnel mouth, the Swansea, Kitchen, Enterprise, Songbird, Hiawatha, Eureka, Jumbo No. 2, and Jumbo No. 3



CLAIM BOUNDARIES
AND
PRINCIPAL UNDERGROUND WORKINGS
OF THE
ENTERPRISE, NEWMAN, STEPHENS, AND RICO-ASPEN MINES

Scale
100 0 100 200 300 400 500 1000 FEET



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veins. The development on the lodes rarely extends for more than 200 feet below the blanket limestone, being practically confined to two levels, one known as the Tunnel level, and one a hundred feet above it, known as the 100-foot level. Immediately above this limestone and following the dip and undulations of its upper surface, is a most intricate and almost entirely irregular labyrinth of drifts and stopes known as the "contact" workings (see Pl. XXXVI).

Connections exist through drifts with the workings of the Newman and Rico-Aspen mines, and also with the surface through the Laura, Stanley, Jumbo, and Enterprise shafts, and an air shaft between the Laura and Stanley. Of these, the air shaft only is now kept open as a manway.

Northeasterly lodes.—These are nearly vertical fissure veins, usually of small size and of very simple type. They rarely exceed 18 inches in width, and the average is probably about 6 inches. As a glance at the map (Pl. XXXVI) shows, they are neither straight nor parallel. Their general courses are as follows:

Courses of northeasterly veins in Enterprise mine.

Vein.	General strike.
Swansea	N. 48° E.
Kitchen	N. 53° E.
Enterprise	N. 50° E.
Songbird	N. 47° E.
Hiawatha	N. 40° E.
Eureka	N. 62° E.
Jumbo No. 2	N. 34° E.
Jumbo No. 3	N. 32° E.

Besides these are the Newman and Intermediate veins, which have been worked to some extent, and many smaller veins that have not proved worthy of development.

The northeasterly veins are so nearly vertical, have been explored through so short a vertical range, and in that distance have frequently shown such variation, or even reversal of inclination, that direct observations of dip angles in the workings now accessible are usually of very little value. It seems to be fairly certain that the general dip of the Swansea is northwest at an average angle of 75° to 80°. The Jumbo No. 3 for about 80 feet below the Enterprise limestone is on the whole practically vertical where seen. Below that it has a decided dip to the southeast of 70° or 75°. The other veins are all nearly vertical, but whether the average dip in any case is southeast or northwest can not be easily decided. The map of the workings indicates a steep southeasterly dip for the Jumbo No. 2, Eureka, and Enterprise veins, but throws no clear light on the Kitchen, Songbird, and Hiawatha veins. Rickard states that "the Songbird dips west flatly;"[1] but in his general section[2] he shows the Songbird first dipping northwest and then turning and dipping strongly southeast. There are other discrepancies in his descriptions and diagrams which detract from their usefulness.[3]

For all practical purposes it is perhaps sufficient to consider the veins as nearly vertical on the whole, with frequent variations to either side of the vertical plane. With all save the Swansea, and perhaps the Kitchen vein, these departures appear to give steep southeasterly rather than northwesterly dips.

The fissures in which these veins formed were opened by very moderate faulting, which so far as observed was normal in character. No case has been noted in which the vertical displacement is over 10 feet, and it is generally much less. In most instances the faulting has thrown down the beds on the southeast side of the fracture. According to the unpublished observations of Mr. Tower, however, the faulting on the Songbird and Jumbo No. 2 veins resulted in a drop of the beds on the northwest sides of the fissure of from 3 to 7 feet. Owing to the condition of the workings, there was no opportunity of verifying these observations in 1900. Rickard's detailed transverse sections[4] make both the Songbird and Jumbo No. 2 veins dip to the northwest and show normal faulting, thus agreeing with Tower and with the general rule of the faulting. But his general section, as already pointed out, shows these veins with a general southeasterly dip. Whether one or other vein actually dips to the southeast or northwest, it may be safely assumed, in the case of veins so nearly vertical and where normal faulting is often plainly shown, both on the principal veins and in small stringers in the country rock, that the stresses which originally opened the fissures were such as produce normal, rather than reversed or thrust faulting.

In the nature of their filling and in vein structure, the northeasterly fissures resemble each other closely, so that the description of a typical vein will apply with little or no modification to all the others. Such a typical vein is the Jumbo No. 3. This, as well as the Eureka, Songbird, and Jumbo No. 2 veins, has been graphically described by Rickard[5] in a series of sketches made from time to time as the development of the mine proceeded. Two of his drawings of the Songbird and Eureka, are here reproduced as figs. 45 and 46 in order to show the character of the veins, and for the reason that good exposures are no longer visible.

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[1] Loc. cit., p. 947.

[2] Loc. cit., p. 974, Fig. E.

[3] For example, on pp. 919-920, he states that the Enterprise, Jumbo No. 2, Jumbo No. 3, and Hiawatha veins all dip *northwest*, while the Kitchen, Swansea, and Songbird veins dip *southeast*. In this case the words *northwest* and *southeast* should plainly be transposed.

[4] Loc. cit., figs. 3, 4, and 5, pp. 920, 921, and 923.

[5] Loc. cit., figs. 3-10.

The Jumbo No. 3 vein was studied in 1900 at several points in the drifts and stopes extending northeastward from the Group tunnel to the Laura cross cut. South of the Group tunnel the possession of this vein was formerly disputed by the Enterprise and Rico-Aspen companies. The bulk of the ore was extracted by the latter, and is reported to have been sometimes over 3 feet wide and rich in argentite and other high-grade silver minerals.

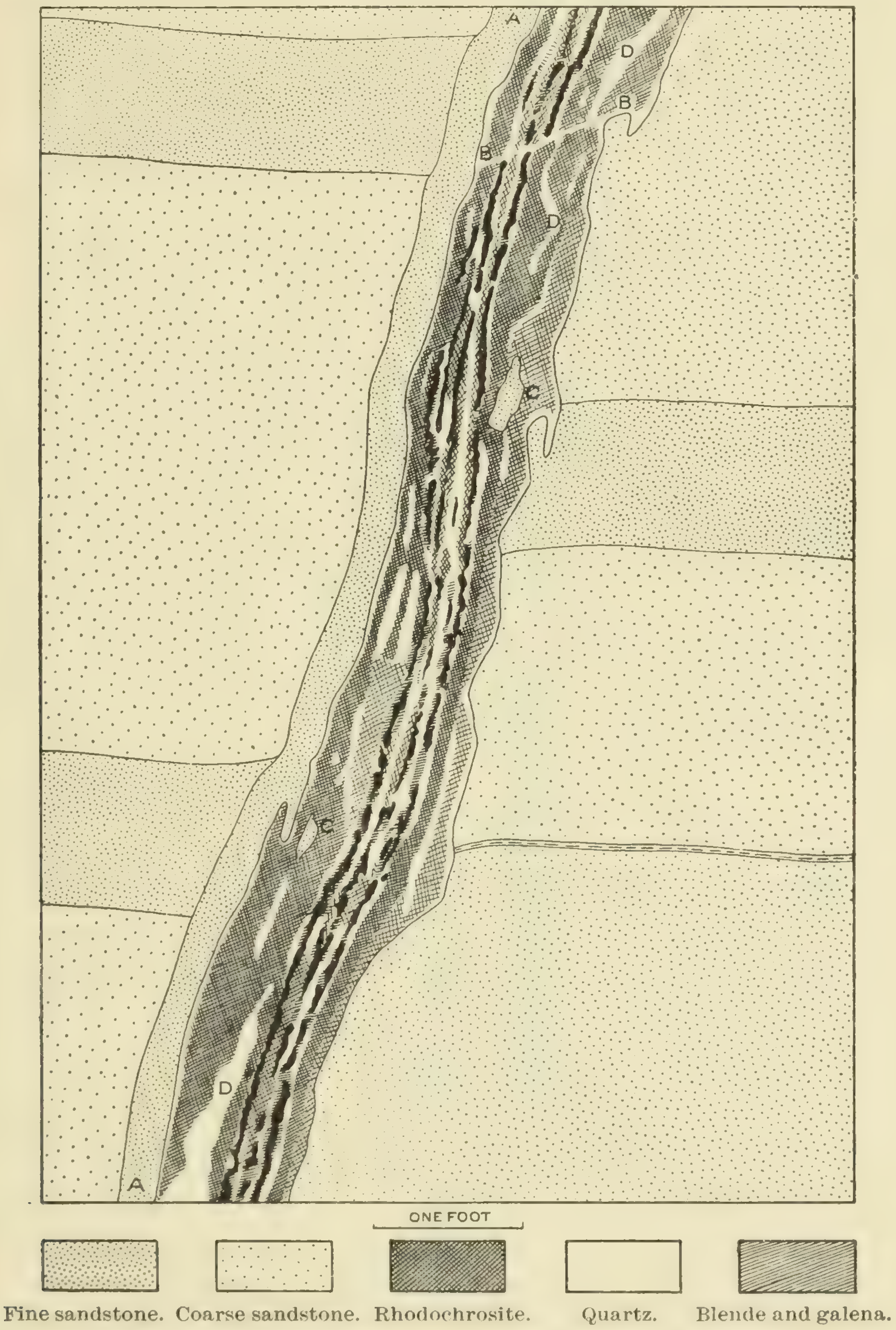

FIG. 45.—Section across the Songbird vein (after T. A. Rickard).

Northeast of the Group tunnel the vein is usually a solid tabular mass or plate of quartz, rhodochrosite, and ore (see Pl. XXVIII, *B*).

It is generally less than 14 inches in width, and is, as a rule, adherent or frozen to the walls of the fissure. Such ore is always banded, and the colors of the component minerals render this structure unusually striking, as may be very imperfectly seen from the illustration, Pl. XXX. But, while striking and beautiful on fresh exposures of the vein, this banding is hardly so regular as Rickard's drawings indicate. Individual bands can rarely be followed far before they die out or coalesce with others. Nor does the succession of minerals from the walls in toward the medial plane of the vein follow any observable regular sequence. Usually quartz was first deposited on the fissure walls, but often rhodochrosite was the earliest mineral to form. The

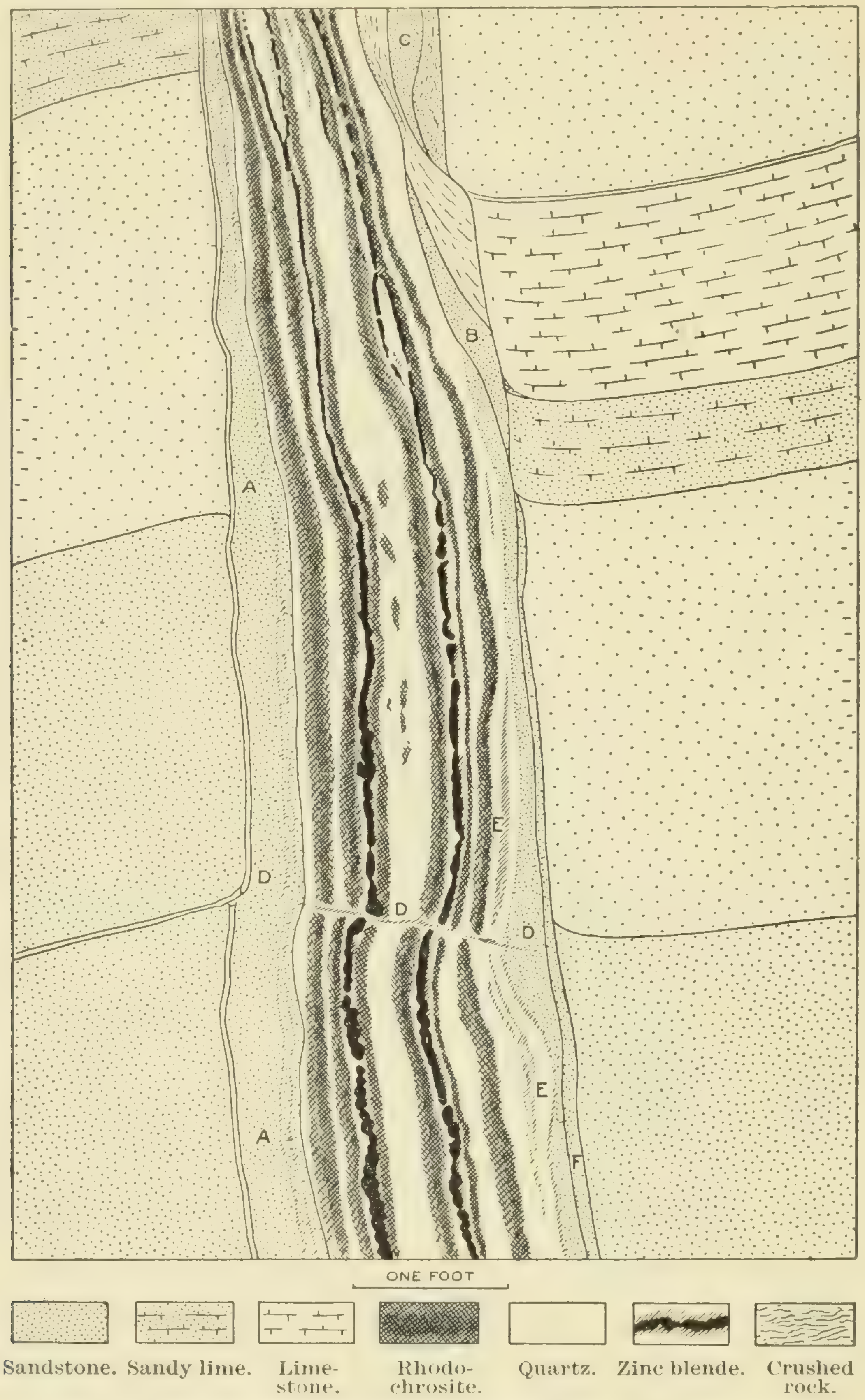

FIG. 46.—Section across the Eureka vein (after T. A. Rickard).

ore minerals, galena, pyrite, chalcopyrite, and sphalerite, occur in all portions of the vein, but tend to be more abundant in the middle. There are usually numerous small vugs along the medial plane of the vein, and in these occur the rich silver minerals proustite, argentite, stephanite (?), and polybasite, and occasionally free gold and silver, which form the richest ore. Sometimes there are other planes of vugs or sutures in the vein, but, as a rule, the medial one only carries rich ore.

Most of the banding, as far as observed, is depositional, i. e., constitutes true banded structure rather than ribbon structure.[1] The minerals have been deposited in successive more or less irregular crusts on the fissure walls until at last only a narrow crevice was left along the medial plane of the vein, in which the richest ore was finally deposited (Pl. XXX). But the deposition was not entirely a simple, uninterrupted process. There is unmistakable evidence, not only along the Jumbo No. 3 vein, but also in others of its class, that the fissure after having been wholly or partly filled with ore, was reopened, usually next to one wall, and the opening again filled by fresh deposition. As far as could be determined, this latter filling always consists of nearly barren white quartz carrying a little pyrite. In some parts of the fissure this reopening and redeposition took place at least twice. Other portions show no signs of it. It was sometimes connected with the local development of ribbon structure on a small scale (see Pl. XXXI).

Thus far the Jumbo No. 3 has been described as a fissure vein of the simplest type. But it does not always retain this character. It is sometimes associated with parallel sheeting of the country rock and is then apt to split up into two or more stringers. This structure is well shown at the north breast of the 150-foot (intermediate) level, near the Laura crosscut, and is illustrated in fig. 40, page 257, where, it will be noted, the vein dips locally to the northwest.

The characteristics of the vein so far described are those which obtain above the Tunnel level and below the Enterprise limestone. In all the northeasterly veins the ore at a certain fairly constant distance below the Enterprise limestone becomes too low grade to pay for working. The veins continue downward and carry pyrite, chalcopyrite, sphalerite, and galena, but the rich ores of silver which made the upper portions profitable are no longer found. The depth at which this change takes place is apparently not dependent upon the topographic surface, but is related to the so-called "contact" resting on the blanket limestone, and with reference to the latter is remarkably small. The relation of the lode pay shoots to the overlying blanket is shown in Pl. XXXVII, consisting of longitudinal sections of the more important northeasterly lodes. Farish[1] describes the vein as follows:

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[1] Following Lindgren. See gold-quartz veins of Nevada City and Grass Valley, etc.: Seventeenth Ann. Rept. U. S. Geol. Survey, Pt. II, 1896, p. 129.

> It has been stated that the deepest workings on the veins in the territory under consideration are 200 feet below the "contact limestone." At this depth on the "vertical pay veins" the vein filling is a glassy white quartz. The quartz contains numerous vugs, some of which are of considerable size. These cavities are usually lined with handsome quartz crystals. The metallic minerals are not plentiful, and consist of pyrite (in cubes) associated with some chalcopyrite. Raising on the vein, the quartz becomes less glassy, fewer vugs are found, and rhodochrosite appears. The pyrite is more abundant and becomes finer grained, and sphalerite, galena, and massive tetrahedrite appear. Continuing upward toward the "contact," the proportion of metallic minerals steadily increases, and with such increase the gold and silver contents become, in a marked degree, greater.

Rickard says that "the ore is confined to the pay veins for a depth of 100 to 175 feet below the contact." Mr. Percy S. Rider, in conversation with me, placed the maximum depth to which pay ore extends at about 125 feet below the Enterprise limestone.

Passing upward, the Jumbo No. 3 vein retains the character already described and carries good ore until a point is reached about 30 feet below the blanket. Here the vein begins to carry less ore—grows lean, as the miners say—and when the thin-bedded sandstones and shales are reached, below the blanket limestone, it splits up into small, irregular stringers, which are valueless as ore. This division into small stringers as the blanket is approached is common to all the northeasterly veins. But in the Swansea, Eureka, and Enterprise veins some of these stringers carried high-grade ore up to the blanket.

Certain irregularities exhibited by the northeasterly lodes in connection with the northwesterly lodes will be discussed after the latter have been themselves described; and the exact relation of the northeasterly veins to the blanket and the question of their possible continuance above it can be more clearly understood when that very interesting feature has been in turn examined.

Northwesterly lodes.—These, familiarly known as "cross veins" or "barren veins," are at the present day better exposed and more available for study in the Newman mine than in the Enterprise. But as the latter has to a certain extent become classic ground, and as these veins have been an important factor in ore deposition, they are deserving of considerable attention, even when the best opportunities for their investigation have gone by.

The strikes of the northeasterly veins range from nearly north and south to about N. 45° W. Their dips range from vertical to about 40°, and may be northeast or southwest, although the former is more common. As a rule, the dips are lower than in the northeasterly veins. Very commonly these veins occur in groups of two or more, spaced a few feet apart and possessing nearly parallel strike and dip. They

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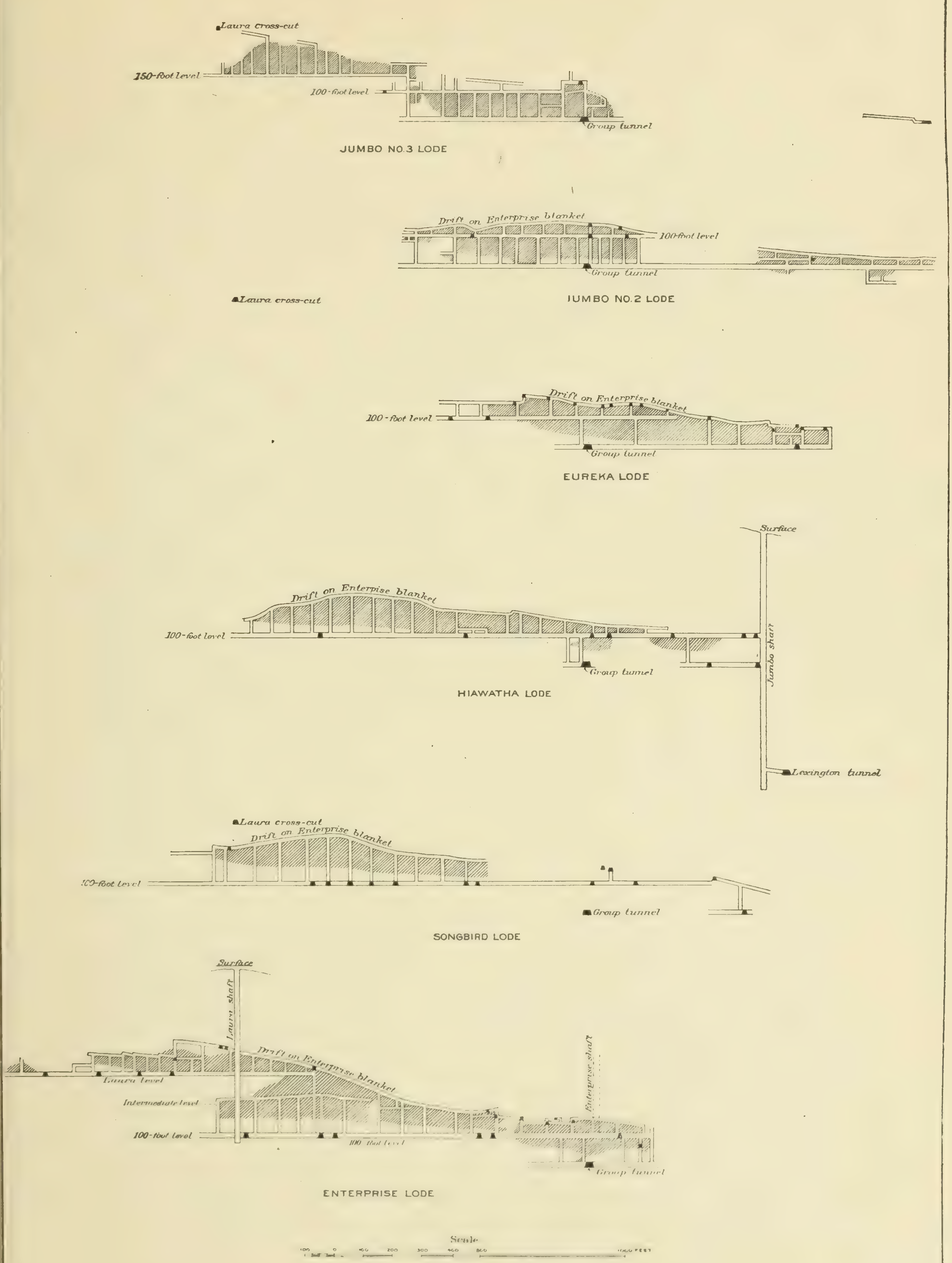
[1] Loc. cit., p. 161.



LONGITUDINAL SECTIONS OF THE PRINCIPAL NORTHEASTERLY LODES OF THE ENTERPRISE MINE.

Showing undulations and faults in the overlying Enterprise blanket and the extent of the lode ore bodies. Shaded areas indicate stopes.

are very numerous, and are cut at frequent intervals by the long northeasterly drifts. But unless the northwesterly vein is itself drifted upon, such exposures are not sufficient to give the general course and dip, nor do they permit the certain identification of any given northwesterly vein from one drift to another across unknown ground. Such identification is rendered more difficult by the similarity of these veins and their frequent occurrence in groups or zones.

One important zone of northwesterly veins, with a general strike of N. 17° W., and an apparent easterly dip, lies just east of the long crosscut on the 100-foot level, passing east of the Enterprise shaft and crossing most of the northeasterly veins nearly at right angles.

Another prominent northwesterly lode is that which Rickard[1] has represented as faulting the Hiawatha and Songbird veins. This same fissure has been followed apparently in the Kitchen crosscut, between the Songbird and Swansea veins. Toward the southeast its course and identification are less certain. It probably forms one of a group of northwesterly veins which cross the Jumbo No. 3 vein just northeast of the line of the Group tunnel and extend southeasterly toward the Vestal shaft of the Rico-Aspen mine.

A third strong northwesterly lode crosses the north drift on Jumbo No. 3, about 450 feet northeast of the Group tunnel. This fissure has been followed by a crosscut from the Jumbo No. 2 vein to within 200 feet of the Hiawatha, and appears to be identical with a strong lode crossing the Enterprise drift north of the 12½ raise.

A fourth prominent northwesterly lode, having a nearly north and south strike and easterly dip of about 45°, crosses the Eureka vein about 300 feet northeast of its junction with the Jumbo No. 3, and is well exposed in the Laura crosscut.

Besides those mentioned are many other veins belonging to this system, some of which will be referred to when the relation between the northeasterly and northwesterly lodes are described.

The northwesterly lodes vary greatly in breadth, from a mere veinlet or "seam" up to 2 feet, or, according to Farish,[2] 3 feet. In the character of their filling they show, with two or three exceptions, a marked difference from the northeasterly veins. They consist of white quartz, with rarely a little rhodochrosite. The only metallic mineral usually observed in them is pyrite, which may carry a trace of gold and a few ounces of silver, but is not regarded as ore. A striking feature of all these veins which were seen in 1900 is the shattered and crushed condition of their quartz. This can nearly always be picked down with perfect ease and is often reduced to a white powder—"sugar quartz." More or less gouge, formed by the attrition due to recent movement, is rarely, if ever, absent and may constitute the greater part of the material between the fissure walls.

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[1] Loc. cit., fig. 23, p. 948.

[2] Loc. cit., p. 157.

Like the northeasterly veins, the northwesterly lodes have been formed with the accompaniment of slight faulting. The greatest vertical displacement recorded has been 25 feet,[1] but it is generally much less than this, and may be only a few inches. In the case of these lodes it is impossible to say how much of this movement has taken place after the original deposition of the quartz. It is the algebraic sum of all the approximately vertical movements since the fissure was first formed.

Relation of the northwesterly to the northeasterly lodes.—It is not intended here to discuss this relationship, concerning which very different opinions have been held, but merely to present the facts upon which rests the more general treatment found on pages 268 to 272 of this report.

It has been found that in following the northeasterly lodes they are frequently lost at a point where crossed by a northwesterly fissure. It is commonly assumed by the miners that the former vein is faulted by the latter. In such cases the ore-bearing vein is cut off sharply by the barren northwesterly lode, and by drifting to a greater or less distance along this barren fissure a vein is usually found which is regarded as the continuation of the faulted lode. A notable case in point is the behavior of the Hiawatha vein on the 100 level, about 350 feet northeast of the line of the Group tunnel. At this point the Hiawatha, on drifting northward, was found to be cut off by a strong northwesterly lode. Rickard's and Farish's interpretations of this feature and the steps taken to recover the faulted vein are shown in figs. 47 and 48. According to Rickard, the fault has resulted in a lateral separation of about 175 feet in the case of the Hiawatha and of considerably less than 20 feet in the case of the Songbird, both nearly vertical lodes. It will naturally be asked, On what basis are the supposedly dissevered portions of a vein identified on opposing sides of a

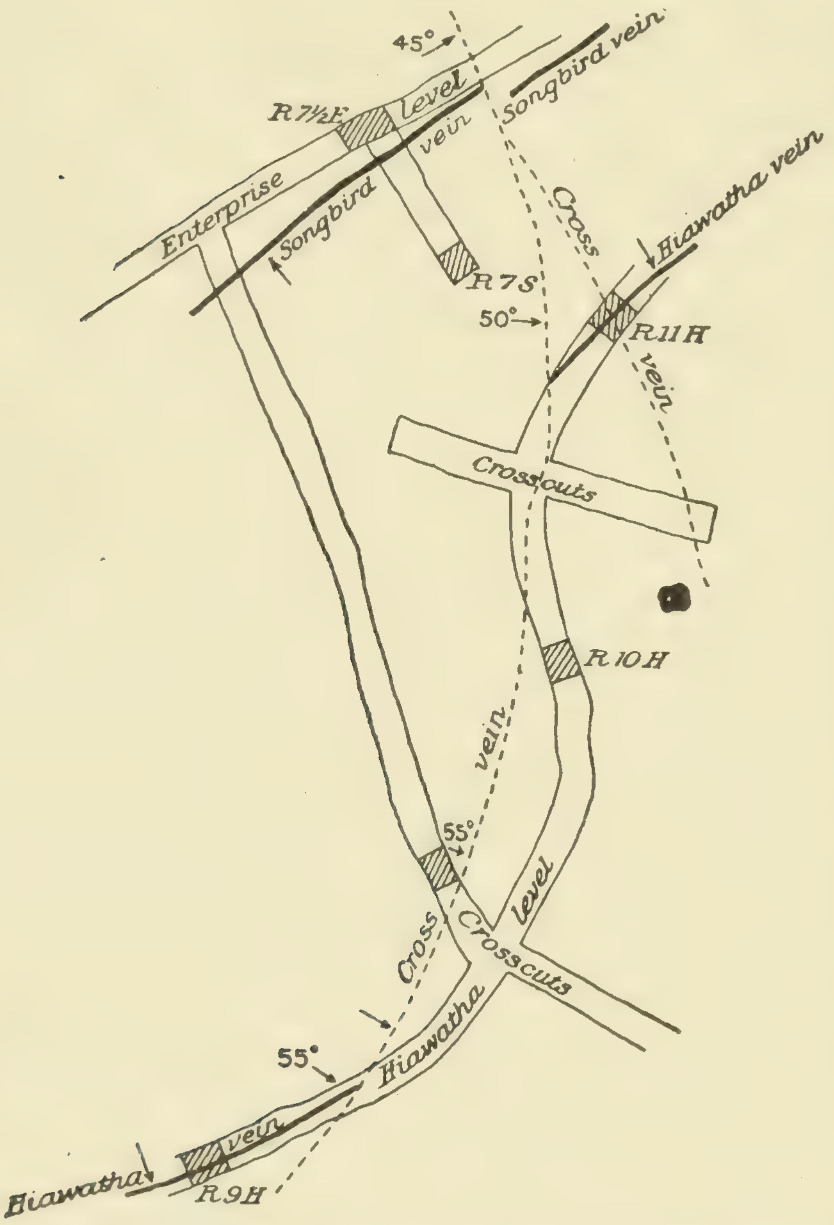

FIG. 47.—Relations of Hiawatha, Songbird, and Enterprise veins, as interpreted by T. A. Rickard.

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[1] Farish, loc. cit., p. 157.

faulting northeasterly fissure? It may be answered that not only are no certain criteria known where occur so many nearly vertical veins of like character, but that in some cases obviously incorrect identifications have been made, and are believed in by the miners to-day.

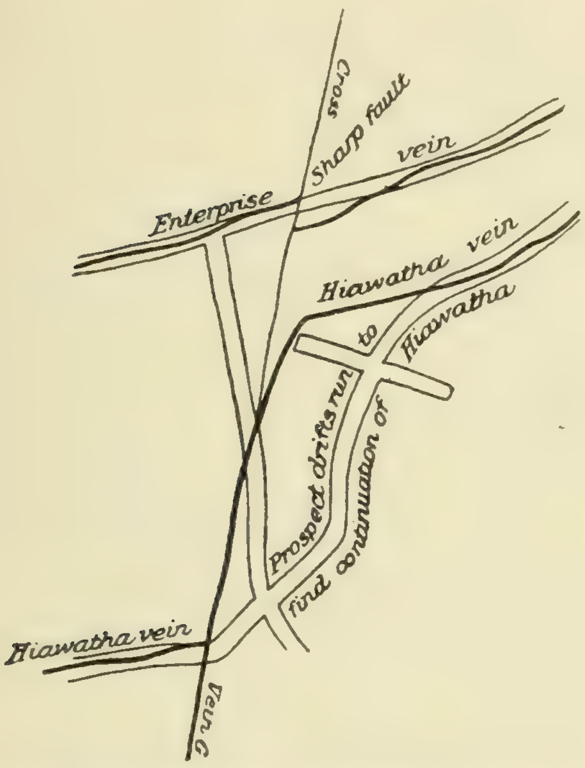

FIG. 48.—Relations of Hiawatha and Enterprise veins, as interpreted by John B. Farish.

The Swansea vein, as seen on the 100-foot level, about 300 feet northeast of the Group tunnel, is cut off sharply by a northwesterly fissure and apparently faulted, with a lateral separation or offset of about 25 feet. The faulting vein dips northeast at an average angle of about 70°, and carries a little low-grade ore. This ore, however, is a breccia consisting of fragments from the Swansea vein, cemented by barren white quartz. This fault is shown in plan on Pl. XXXVI.

About 475 feet north of the Group tunnel, on the 100-foot level, the Jumbo No. 3 vein is cut by one of the prominent northwesterly lodes previously mentioned, and is apparently faulted, its northern continuation being thrown into the hanging wall. From this point northward for a distance of 350 feet, to the supposed junction of the Jumbo No. 3 and the Eureka veins, very little good ore was found. As shown by the sketch plan, fig. 49, the veins in this portion of the mine show many complications, which can not be wholly unraveled with the extent and conditions of the workings as they are at present. There are at least three nearly parallel northeasterly veins known, any one of which may be the actual continuation of the fissure known farther

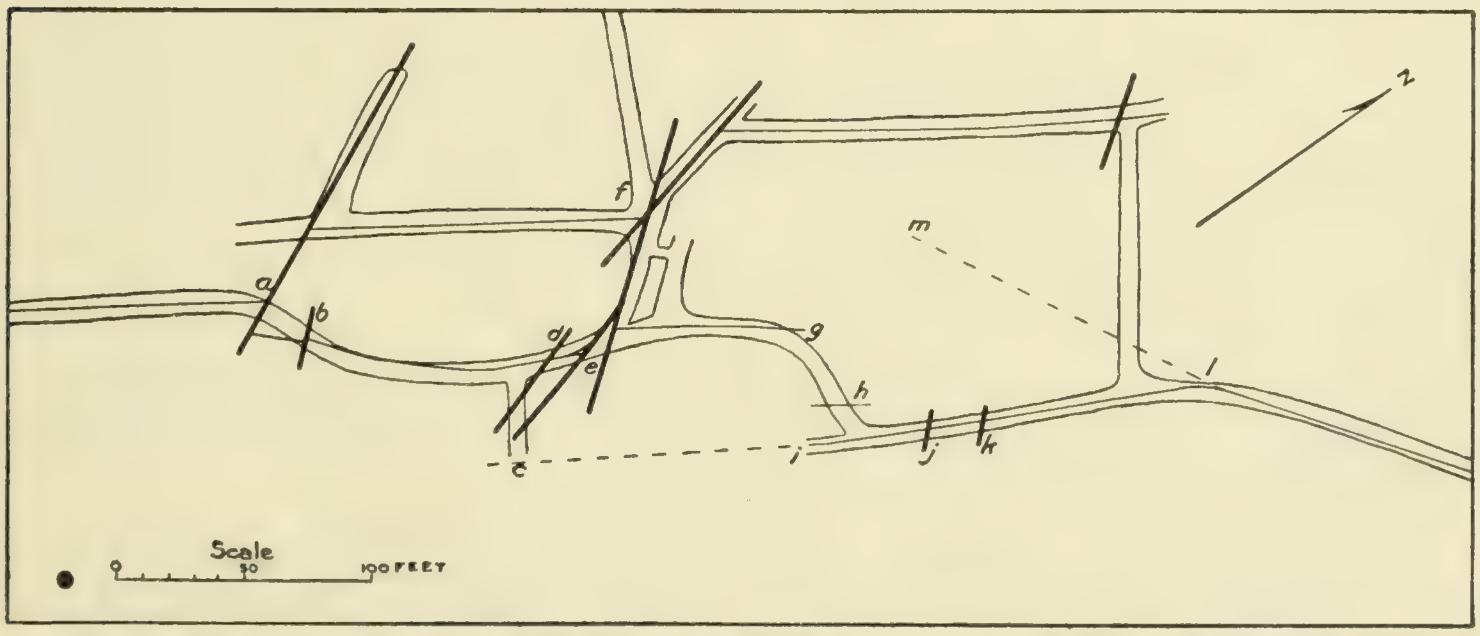

FIG. 49.—Sketch map of a portion of 100-foot level of the Enterprise mine, showing probable relations of the Jumbo No. 3 and other northeasterly veins (in light lines) to the northwesterly lodes (in heavy lines).

south as the Jumbo No. 3 vein. At the point marked *e* in figure 49, the vein *b–d*, supposed to be the Jumbo No. 3, swings abruptly northwest and follows the course of a northwesterly fissure from *e* to *f*, and possibly beyond. This sudden change of the vein from one fissure to another was noted by Farish[1] and was considered by Rickard[2] as an instance of drag due to faulting. Neither observer appears to have been strictly correct in his interpretation. There seems to be little doubt but that the vein *b–d* was originally deflected into the fissure *e–f*, as is shown by the way in which the banded structure and characteristic minerals of the northeasterly vein curve into the new direction. But it is also true that there has been some later movement along *e–f* whereby this original vein has been somewhat broken, and following which a second generation of vuggy white quartz was formed—the usual filling of the northwesterly veins. Still later this composite vein has been crushed and in places reduced to sugar-quartz by the movements which have so strikingly and generally affected the northwesterly veins. This was the only case observed in 1900 where a northeasterly vein could be clearly seen deflected for some distance into a northwesterly fissure. But several other examples have been cited by Farish.[3]

The foregoing examples are those which are at present accessible and appear to throw most light on the relation between the northeasterly and northwesterly veins. But this relation can be better understood and will be more fully illustrated in the description of the Newman mine.

That the tenor of the northeasterly veins is influenced in some manner by the northwesterly fissures is beyond reasonable doubt. Rickard[4] states that "it is common to find ores of more than average grade in the pay veins where they are broken by the cross veins." Superintendent Percy S. Rider informed me that when a northwesterly fissure is encountered intersecting a northeasterly vein, the ore in the latter becomes suddenly poorer or suddenly richer, and the testimony of the miners generally confirms this statement. Mr. Rider also believes that the ore in the northeasterly vein always changes from foot to hanging wall, or vice versa, at such an intersection. But this is certainly far from a universal rule.

The blanket or "contact."—This peculiar and interesting feature of the Enterprise mine has already been referred to and its general position in the sedimentary series pointed out. It is largely an unconsolidated breccia, from a few inches to 20 feet in thickness, which rests bed-like upon the blanket limestone. Its average thickness appears to be about 6 feet. Sometimes the entire thickness is made up of a jumbled mass of small shale fragments embedded in still more finely comminuted shale. In its upper part this breccia passes with no sharp separation into disturbed and crumpled black or dark-gray shale, which becomes less broken in its upper part. Sometimes considerable fragments of soft sandstone are mingled with the shale-flakes in the "contact" breccia. When such is the case the rock immediately above the blanket is usually a bed of similar sandstone, the brecciation having apparently involved the entire thickness of the black shale and a part of the overlying sandstone. There has undoubtedly been some movement within the breccia due to faulting parallel with the bedding, as shown by slickensiding and soft, tough gouges. But this motion has been local, and the blanket as a whole can not be regarded as a simple fault-breccia. In structure and general appearance it suggests a mass of shale and sandstone débris which has been dumped into an empty space. So close indeed is this resemblance that in the New Year mine, where an old tunnel has been filled with waste from more recent workings, a section of this artificial filling perfectly reproduces the characteristic appearance of the blanket breccia.

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[1] Loc. cit., fig. 9.

[2] Loc. cit., p. 948.

[3] Loc. cit., pp. 158–159.

[4] Loc. cit., pp. 977–978.

Not all of the Enterprise blanket, however, is made up of this breccia. Its lower part, resting directly upon the blanket limestone, is commonly a soft, gray, pulverulent, silty material, containing occasional fragments of shale. It sometimes shows nearly horizontal lamination, indicative of a water-laid origin. This deposit varies much in thickness and does not appear to be always present. Between it and the blanket breccia there is no well-marked plane of division.

In certain portions of the Enterprise workings the position usually occupied by the blanket is taken by masses of gypsum, in places at least 15 feet in thickness. A large mass of this gypsum was encountered in the "contact" workings on the south side of the Group tunnel, but could be reached in only one place in 1900. It rests directly upon the blanket limestone, or is separated from it by a variable thickness of the gray, sandy material already referred to. At the only point seen in the Enterprise mine the gypsum showed typically irregular solution forms, and in its relation to the "contact" breccia resembled a mass of snow buried and slowly and irregularly melting away under a landslide. When mining was in progress in this portion of the mine, cavities in the gypsum large enough for a man to crawl through were frequently encountered. The general relations of the "contact" and gypsum are shown in fig. 42, page 275.

Although, on the whole, the blanket, like the strata between which it lies, dips to the southeast at about 10°, yet it presents many local irregularities. Undulations are frequent. One of the most important of these, known as the "Laura swell," is said to occur about 300 feet southwest of the Laura shaft and to be of the nature of a monoclinal fold striking a few degrees west of north. According to Mr. P. S. Rider, in following the "contact" northeast toward the

Laura shaft it is found to rise steeply for a distance of about 60 feet along the incline and then resume its usual gentle dip toward the Laura shaft. Northeast of this Laura swell very little ore was found in the blanket, and the approximate line of the flexure can be recognized on the map of the mine as the northeastern limit of the extensive "contact" workings (see Pl. XXXVII).

Toward the southeast the blanket, as it is followed under Dolores Mountain, near the breast of the Group tunnel, becomes thinner, shows less brecciation, and carries but little ore. No further extensive exploration of it in this direction can be undertaken from the Group tunnel level. The Lexington tunnel, however, 400 feet below, is at its face (which is nearly under that of the Group tunnel) still well below the blanket.

About 2,000 feet from its mouth the Group tunnel passes through a flat seam of crushed shale up to 18 inches in thickness. This material rests upon a bed of limestone and is overlain by dark shale. It is, in fact, a lower blanket of limited extent, but similar to the Enterprise blanket above. At this point it is about 100 feet below the latter. At the Enterprise vein the distance is about 140 feet, and this local blanket is said to have carried a little ore alongside the lode.

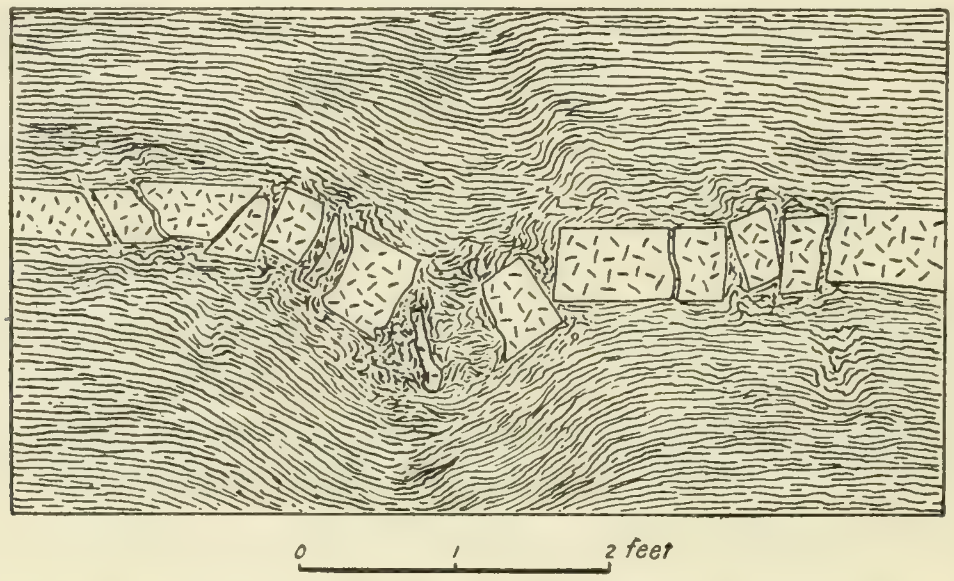

FIG. 50.—Small porphyry sheet intruded in the blanket shales and broken by subsequent movement, Enterprise mine.

Eruptive rocks.—Although the prevailing rocks of the Enterprise workings are sandstones, shales, and limestones, a few small masses of monzonite-porphyry have been encountered. One of these is a small, irregular dike cutting the sandstones and shales which form the country rock of the Jumbo No. 3 vein near the Laura crosscut. But the porphyry is more commonly encountered as thin, intrusive sheets. One of these sheets, only from 4 to 6 inches thick, was noted within the blanket itself. It had been intruded in the shales before brecciation took place, and was shattered and displaced. A diagrammatic representation of such a broken sheet is shown in fig. 50. A short distance away from the point shown in this sketch the shales and porphyry become more disturbed and pass into the typical brecciated blanket already described, in which the broken fragments of the porphyry sheet have suffered greater displacement than is here shown. Thicker sheets occur in the blanket and in the thinly bedded sediments above and below it. They are usually rather irregular and have been disturbed by minor faulting. Farish[1] has noted and sketched a decomposed porphyry dike nearly parallel to the Eureka vein and only a few feet from the latter. This dike was not seen in 1900. Farish has described it as being later than the ore. This appears highly improbable, and his error has very likely come from a failure to distinguish planes of faulting from true igneous contacts. One instance was seen in 1900 where a portion of an intrusive sheet had been faulted down so as to cut off the ore in the blanket and give somewhat the appearance of a dike. Its true nature, however, was established by drifting under it a few feet lower down.

Blanket ore bodies and their relation to the lodes.—In 1900 all the known ore bodies in the blanket had been extracted and the stopes allowed to cave. Fortunately, however, the essential facts connected with the blanket ore bodies have been established by Farish and Rickard and are borne out by actual later exploration. These facts may be briefly stated as follows:

Both the northeasterly and northwesterly lodes as they approach within 20 or 30 feet of the overlying blanket begin to split up into stringers, and in the thin-bedded sandstones, shales, and blanket limestone which immediately underlie the blanket these stringers become a network of minute veinlets. The veinlets belonging to the northeasterly lodes usually carry rich ore, but those belonging to the northwesterly lodes are, like the latter themselves, practically barren. The "contact" ore occurs in nearly horizontal masses, capping both the northeasterly and northwesterly lodes. These bodies are from a few inches to 5 or 6 feet in thickness and up to 35 feet in breadth. The ore usually rests directly upon the blanket limestone and has been deposited by replacement of the blanket, particularly of the gray, pulverulent material in its lower part. These general relations are diagrammatically shown in fig. 43, page 291, which is an ideal section across a northeasterly vein and its blanket ore body. Although the ore bodies have been mined out, the behavior of the veins as they approach the blanket may be observed at several points in the mine. The ore bodies, as a rule, have proved larger and richer above some of the barren northwesterly lodes than above the northeasterly veins. But according to Rickard[2] not all of the northwesterly lodes ("cross veins") are capped with ore. The strata beneath the blanket ore bodies generally show greater faulting in the case of northwesterly lode fissures than in connection with northeasterly fissures, and the bulk of the ore lies on the downthrown side (see fig. 43).

The lodes are not known to extend above the blanket limestone. Above the northwesterly lodes, fissures showing evidence of recent movement sometimes extend upward through the overlying sediments to a distance of 20 feet, and possibly more. But these fissures never carry ore, and may simply be due to post-mineral movement along the lodes below them.

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[1] Loc. cit., p. 160, and fig. 10.

[2] Loc. cit., p. 962.

It is known that veins occur on the west slope of Dolores Mountain above the blanket horizon, on the Lone Tree and other claims. They are reported to contain much calcite and some low-grade galena, but have been only slightly exploited, and appear to have no connection with the lodes known in the Enterprise workings. They have never been identified with any veins below the blanket. According to Mr. J. O. Campbell, a vein was cut about 200 feet above the "contact" in sinking the Vestal shaft. It contained no marketable ore. On July 12, 1900, a vein of barren white quartz, about 4 inches wide, was cut 6 feet above the blanket near the Swansea vein.

The splitting up of the veins into a multitude of minute stringers as they approach the blanket, and the associated transformation of a simple fault into step-faulting and flexure in the shales beneath and above the blanket, render very improbable the idea that the veins were continued upward into the rocks above. The movement which resulted in moderate faulting below was dissipated above in more or less irregular fracturing, slipping, and bending of the thinly laminated shales and of the soft, plastic blanket.

The ore was deposited in the blanket partly as an interstitial filling, but more largely by direct metasomatic replacement of the blanket material. In the Enterprise ground it occurs also in irregular masses and bunches in the lower part of the massive gypsum, when that material occurs in the blanket. But one case of such occurence was seen, and the ore, containing some quartz and rhodochrosite, had directly replaced the gypsum.

The blanket breccia, the fine gray silty material of its lower portion, and the underlying blanket limestone have undergone much local silicification over certain portions of the northwesterly and northeasterly lodes. The general appearance of such a silicified portion of the blanket is shown in Pl. XXXIV, *A* from a photograph taken in the so-called Bridal Chamber, over an intersection of the Jumbo No. 3 vein with a large northwesterly lode. At this point the blanket limestone has been shattered, and its fragments, as well as those of the overlying dark shale, have been cemented by pure white quartz. The fragments sometimes preserve sharp outlines, but, often rather shadowy, dark patches and mottlings in the white quartz. In either case they are themselves converted into fine quartzose aggregates, and contain no carbonates. As a rule such strong silicification and the deposition of ore in the blanket appear to be antagonistic processes. At least where the one occurs the other is generally lacking, or is subordinate.

The ore.—There is no sharp mineralogical distinction to be drawn in the Enterprise mine between ore from the northeasterly veins and "contact" ore. Galena and sphalerite occur in both and are associated with one or more rich silver-bearing minerals, including polybasite, stephanite,[1] argentite, and proustite. Specimens of rich blanket ore often show polybasite in crystals having the characteristic six-sided, tabular prismatic forms, with triangular striations, that are common with this mineral. Chalcopyrite in comparatively small amounts occurs in both blanket and lode ores, whereas tetrahedrite was noted only in specimens of blanket ore, but may occur in the lodes also, as stated by Farish,[2] and is found in the Selenide lode, in the Rico-Aspen mine. Quartz and rhodochrosite are the common gangue minerals in both classes of ore, the rhodochrosite being regarded as a rough indication of good ore. The latter, however, is less abundant in the blanket ore than in the northeasterly veins. Where the blanket ore has replaced massive gypsum, the clear crystalline variety termed selenite is usually present and forms with quartz and rhodochrosite, the gangue of the ore.

The chief difference between the lode and blanket ores is structural. The lode ores are nearly always banded parallel to the walls of the fissure. The blanket ores, on the other hand, are massive.

The ore of the Enterprise varies widely in value. The average during one year was about 200 ounces of silver and 2 ounces of gold per ton. One carload of about 10 tons is recorded, which was worth about $8,000. The gold has usually ranged from 0.5 to 3 ounces, the silver from 100 to 200 ounces, the lead from nothing up to 10 per cent, and the zinc up to 15 per cent. The silica ranges from about 25 per cent to 60 per cent. Rickard[3] has published the approximate compositions of first- and second-class ores as derived from analyses, and his figures are given below:

Composition of Enterprise ore.

Constituent.	First class.	Second class.
	Per cent.	*Per cent.*
SiO_2	29.2	50–55
Mn	2.0	6–10
Fe	11.8	6–10
Zn	12.0	5– 7
Pb	10.2	2– 3
S	11.6	5– 8
Au	[a] 0.87	[a] 0.3–0.5
Ag	[a] 221.50	[a] 45–75

[a] Ounces per ton.

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[1] Given on the authority of Farish (loc. cit., p. 161), who also records pyrargyrite and native silver. All of the so-called "stephanite" seen in 1900 proved to be argentiferous galena.

[2] Loc. cit., p. 161.

[3] Loc. cit., p. 912.

Rickard remarks that the first class was mostly "contact" ore, while the second class represents the principal product of the veins.

The pyrite which sometimes occurs in the northwesterly lodes usually contains traces of gold and up to 8 or 10 ounces of silver per ton, but is never rich enough to work.

NEWMAN MINES.

Situation and history.—These, which in reality constitute but one mine owned by the Swansea Gold and Silver Mining Company, are also on Newman Hill and are worked through several adits about 1,000 feet south of the mouth of the Group tunnel and at nearly the same level as the latter. The general relation of the workings to those of the Enterprise mine may be seen from the combined plan forming Pl. XXXVI. It was from the Chestnut vein in this property that the first ore was shipped from Newman Hill in 1879, and this discovery led ultimately to the opening of the rich ore bodies in the Enterprise and Rico-Aspen mines. The Newman mines were worked actively in 1884, after a period of idleness, and have continued in intermittent operation to the present time. The blanket ore bodies, however, were not nearly so large as in the Enterprise, and of late years the mine has produced but little ore and has been operated on the leasing system.

Development.—The mines are worked through three principal levels known as the Chestnut, Klingender, and Swansea. All three communicate with the surface through adit tunnels opening on the steep hillside at slightly different elevations. There are in addition various minor drifts and crosscuts at other levels, and fairly extensive "contact" workings. A number of northeasterly lodes have been exploited, of which the more important are the Chestnut, Newman, Newman No. 2, Klingender, South Klingender, and Swansea. The Newman No. 2 is in all probability the same as the Enterprise vein.

Country rock.—In all that concerns country rock and general occurrence of the ore, the Newman mines are merely continuations of the Enterprise mine already described, and it is unnecessary to repeat those general descriptions. The general dip of the beds is about 15° a little west of south.

The lodes.—As in the Enterprise mine, these fall into two classes—the northeasterly veins, which carry workable ore for 200 feet or less below the contact, and the barren northwesterly lodes. The relations of these lodes to each other and to the overlying blanket are in general those observed in the Enterprise, but there are many details obtainable in the Newman mines which can not be so easily seen in their larger neighbor. The northwesterly lodes in particular are not only well developed in the Newman workings, but have been drifted on for long distances, and have thereby been well exposed.

The northeasterly veins in the Newman workings average 6 or 8 inches in width, although much wider portions are said to have been stoped out. Banded structure is a very common feature, and the medial plane of the vein is often marked by vugs lined with quartz crystals. The pay ore has, as a rule, an even more limited vertical range than in the Enterprise mine. Frequently a vein carrying rich ore just beneath the blanket becomes too poor to work at a depth of 70 or 80 feet below the blanket limestone. The ore, unlike that of the Enterprise, is more or less oxidized, the rhodochrosite being partly converted to black oxide of manganese and the argentiferous sulphides partly reduced to native silver.

The Chestnut lode, which is accompanied by two or more nearly parallel lodes, and is crossed by several northwesterly lodes, has been followed in from the surface for a distance of about 450 feet, until it is lost at the intersection of a northwesterly lode known as the Stephens "cross vein." The general dip of the Chestnut is northwest at from 50° to 70°. The lode is partly a sheeted zone comprising 3 or 4 stringers up to 3 inches wide, separated by slabs of country rock. The pay ore, as seen in a stope just above the Chestnut level, was less than 1 foot wide and partly oxidized, containing native silver.

A crosscut, driven north for about 100 feet from the Chestnut lode, cuts several small veins, both northeasterly and northwesterly, and finally taps the Newman vein, which has been drifted upon for about 800 feet. Where intersected by the crosscut, this vein is 8 inches wide and dips northwest at 75°. It is a solid, banded vein, frozen to its walls. Toward the northeast the vein becomes larger and in places fills a sheeted zone as much as 2 feet wide. Comb structure is a common feature. Some portions of the vein have been brecciated and the fragments roughly cemented by quartz, leaving many interstices unfilled. The vein is cut off in this direction by a strong northwesterly fissure known as the Cuarto "cross vein," and its continuation is supposed by the miners to be offset about 90 feet to the north. This point, however, will be more fully discussed later. The supposed displaced portion of the Newman vein, beyond the Cuarto cross vein, is in the line of the Klingender vein, to be described later, and is known as the Newman vein in the Enterprise mine. It is notable in having contained good ore to a depth of 140 feet below the blanket in the Newman workings.

The Newman No. 2 vein is a simple plate of banded quartz, rhodochrosite, and ore, about 6 inches in width and nearly vertical. This vein is not known west of the Cuarto cross vein, near which it splits up into stringers. On the northwest it is slightly offset from the Enterprise vein along a small northwesterly fissure.

The Klingender vein lies from 80 to 100 feet northwest of the Newman vein proper, and has been drifted upon from the surface for a distance of nearly 800 feet. It is practically vertical. This vein, as just pointed out, is directly in line with the supposed offset northeasterly portion of the Newman vein and with the vein known as the "Newman" in the Enterprise workings.

Northwest of the Klingender vein, and with a more northerly strike, lies the Swansea, dipping steeply northwest.

Between the Swansea and Klingender veins are at least five unimportant northeasterly veins. One of these, the South Klingender, appears to be a branch of the Klingender vein, the two joining in a network of stringers. Another, the Swansea No. 3, is regarded as the same as the Swansea vein of the Enterprise mine.

About 150 feet northwest of the Swansea is the North Swansea lode, upon which but little work has been done. Where seen, it is nearly vertical, about 5 inches wide and carries small bunches of ore. In places it fills a sheeted zone 18 inches wide. It is accompanied by some gouge, showing recent movement.

On the whole, the northeasterly lodes in the Newman mines are smaller than the corresponding lodes which have been worked to the northeast, in the Enterprise ground.

The northwesterly lodes in the Newman mines are numerous and often relatively large. To the more important of them, names have been given, such as the Stephens cross vein, the South Klingender cross vein, the Cuarto cross vein, and the James cross vein.

The Stephens cross vein, which is cut in the Chestnut level, nearly 500 feet from its mouth, has a strike of about N. 55° W., and dips northeast at from 55° to 80°. It is usually a simple vein, a foot or so wide, but sometimes divides into two or more stringers, and may then have a total width of 3 feet. It is composed of barren white quartz with a few shadowy dark bands. The quartz is shattered, but not badly crushed. There is usually some gouge in the hanging wall. Where not badly crushed, the quartz sometimes shows regular banding of the kind indicating repeated reopenings of the original fissure, each opening being followed by the deposition of a fresh plate of quartz. The separate plates of white quartz usually show comb-structure and are divided by thin films of material torn away from the wall rock at each fresh reopening.

The South Klingender cross vein intersects the Newman and Klingender veins and dips east at 60°. It is rather smaller than the Stephens cross vein, and is composed of crushed barren quartz and gouge. Its average width is about 6 inches. South of the Newman vein it appears to die out in a few small stringers and in minor adjustments along the bedding planes.

The Cuarto cross vein is the most important of the northwesterly fissures. Its course is 10° or 15° west of north and it dips east at about 65°. It is frequently merely a soft wet gouge, a few inches wide, containing crushed quartz. At other places it is composed of solid white quartz, with a gouge on one or both walls. At its intersection with the South Klingender vein, the Cuarto vein is 2 feet wide, composed largely of gouge and crushed country rock. Ore was formerly stoped from the "contact" over the quartz vein, but the stopes are no longer accessible. The Cuarto fissure is said to fault the "contact" about 20 feet, with the drop on the east side, i. e., a normal fault. As shown in Pl. VI, this northwesterly vein extends into the Rico-Aspen and Enterprise grounds. Above it occurred large bodies of rich blanket ore in the disputed territory between these two mines. The vein is also cut in the Lexington tunnel.

Northeast of the Cuarto is another northwesterly lode, known as the James cross vein. It resembles in its general character those just described, and had a good body of ore from 1 to 4 feet wide above it in the blanket. The structure of the less disturbed portion of this lode, as seen in the southern breast of the James drift, is shown in fig. 41, p. 258. The lodes in the Newman mines are frequently slightly displaced by bedding faults of later date than the vein filling. The maximum displacement of this kind noted was about 1 foot. In all cases observed the upper country had slipped to the south or southeast, i. e., in the direction of the dip.

The blanket.—All work in the blanket of the Newman mines has practically ceased, and but few of the old workings are accessible. But this feature is merely a continuation of that described in the Enterprise. It rests upon the blanket limestone and is overlain by dark shales. The best ore bodies in the Newman mines occurred over the northwesterly veins, but they were not so large as those in the Enterprise.

The blanket, where seen above the intersection of the Klingender and South Klingender cross vein, is a jumble of shale fragments and clayey material, containing angular fragments of sandstone as large as 2 feet wide and 3 feet long. The shale fragments show evidence of recent movement within the mass. Irregularities in the dip of the blanket are common, particularly over the northwesterly lodes. Thus over the Cuarto cross vein the blanket rises steeply to the southwest in a monoclinal flexure for a height of about 25 feet. This roll probably corresponds to a normal fault in the beds below, but no actual fault was discernible in the blanket material itself.

Relation of the northeasterly and northwesterly lodes.—As in the Enterprise mine, the northeasterly lodes are often lost or change in character at the intersection of a northwesterly fissure. In some instances the latter lodes plainly fault the former. In other cases there is no displacement visible. Finally, the northeasterly veins are sometimes interrupted by a northwesterly lode in a manner that can not certainly be ascribed to a simple faulting of one vein by another. It is proposed to illustrate the foregoing statements by several examples.

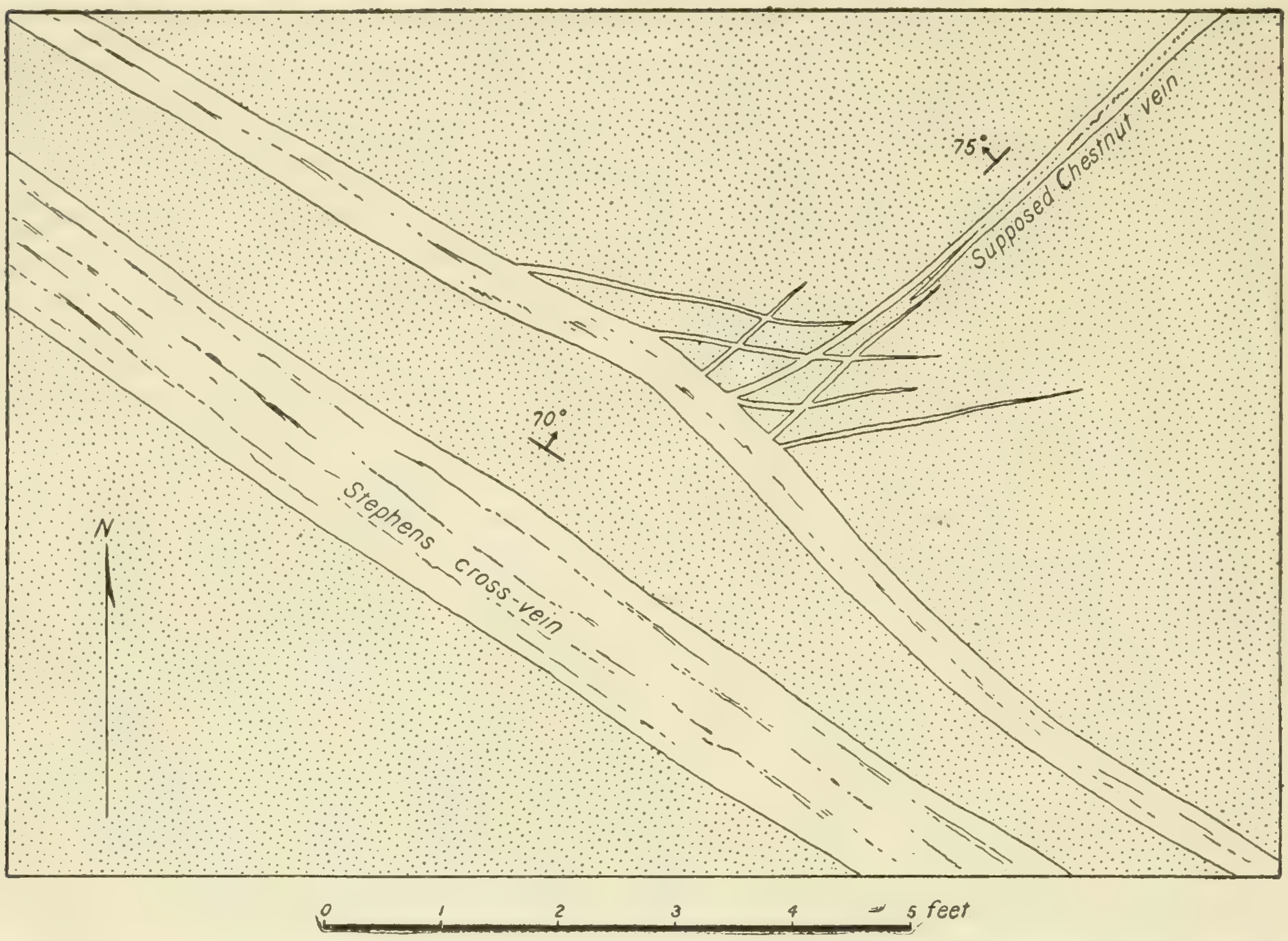


Fig. 51.—Plan of junction of the Stephens cross vein and the supposed northeastern continuation of the faulted Chestnut vein.

The Chestnut vein, at the point where it meets the Stephens cross vein, is cut off sharply and its northeastern continuation is lost. It is supposed by those working the mine that the vein is faulted, and that

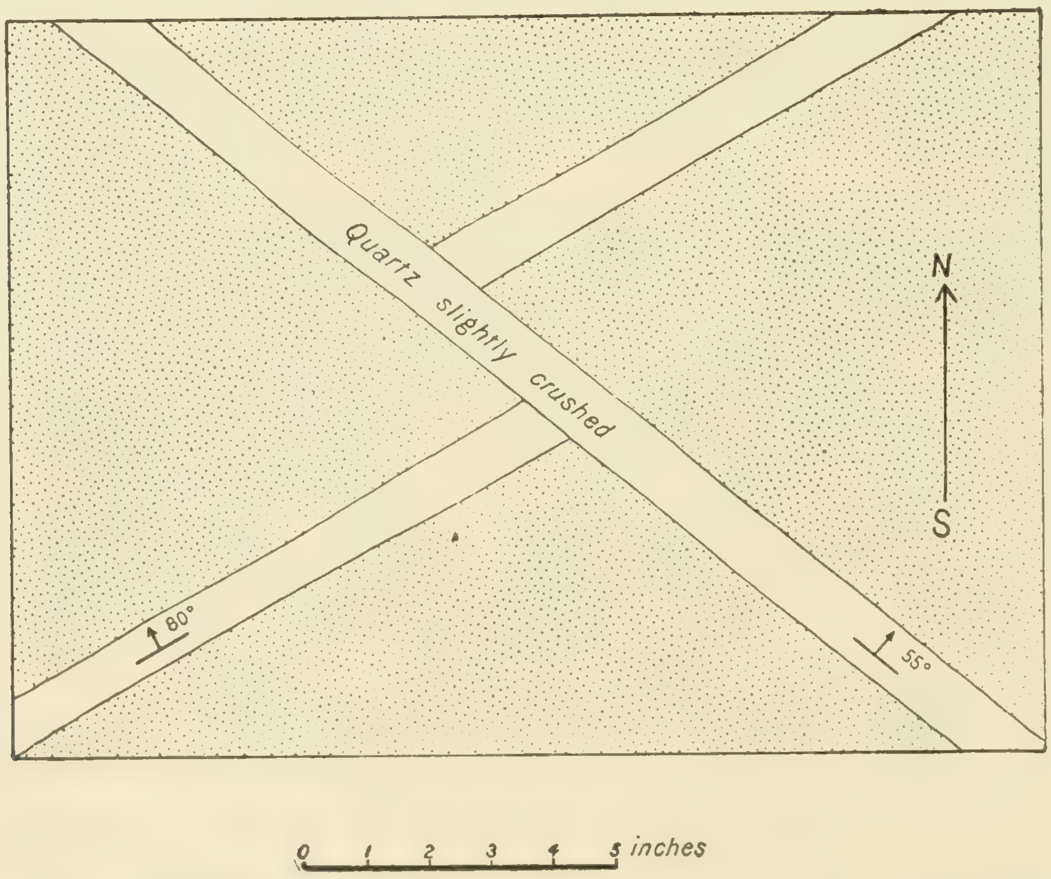


Fig. 52.—Plan of northeasterly stringer faulted by northwesterly stringer in roof of crosscut from the Chestnut vein to the Newman vein, Newman mine.

its northeast portion has been offset about 100 feet to the southwest, where a small vein was found going off northeast from the Stephens cross vein (see map, Pl. XXXVI). This vein begins as a series of small, tight stringers, which gradually collect into a narrow but rich vein. The relation of this vein to the Stephens is indicated in fig. 51. The small stringers shown are perfectly tight, and the Stephens lode itself reveals but slight evidence of recent movement at this point. It is plain from the sketch that the relation of the small northeasterly vein to the Stephens lode is not a simple dislocation of one lode by another. Furthermore, a fault which could result in a horizontal displacement or offset of 100 feet could hardly fail to fault the overlying blanket and the Newman and Klingender veins to a like extent. Neither of these veins, however, shows any apparent faulting by the Stephens lode.

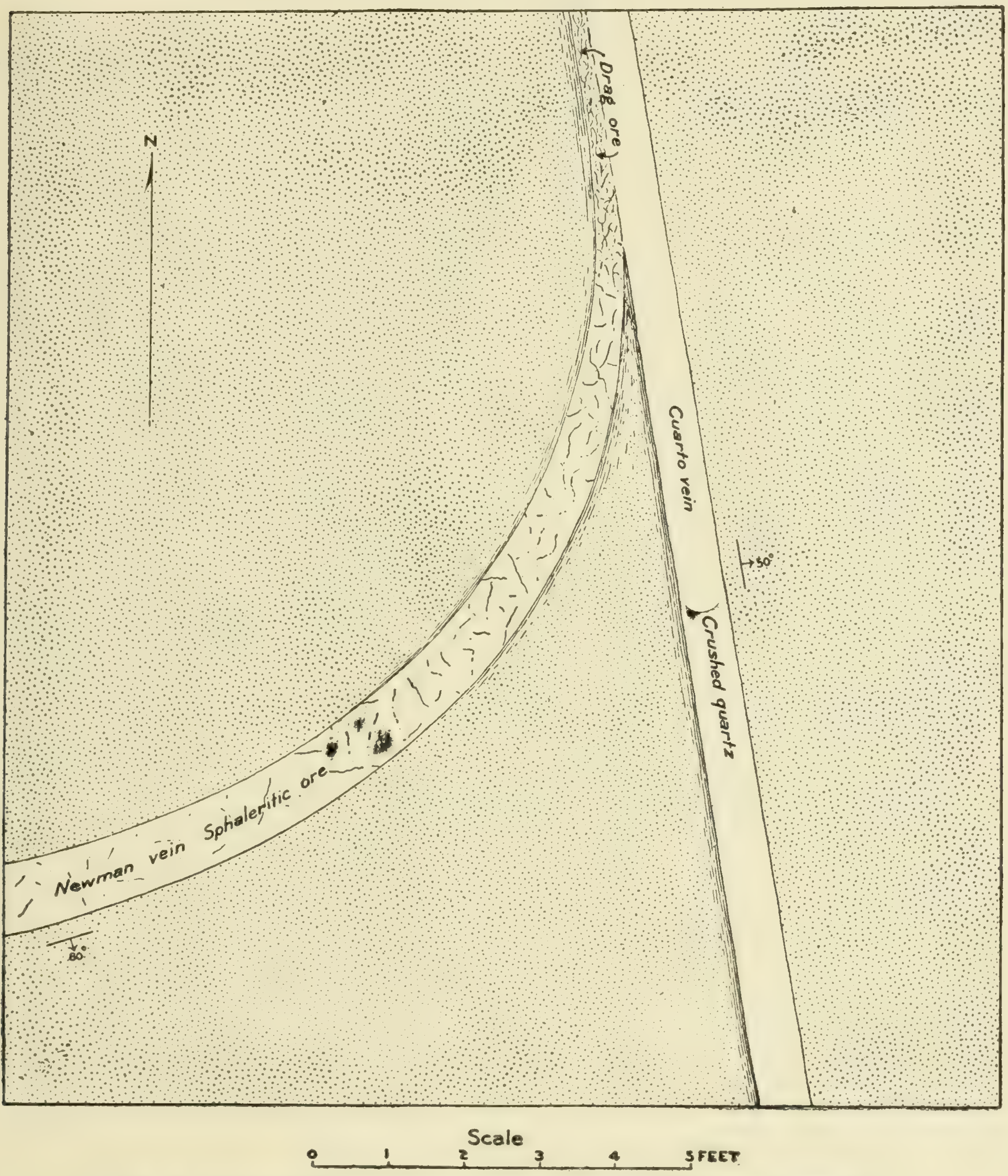


FIG. 53.—Plan of junction of the Newman vein with the Cuarto cross vein.

Several small northeasterly and northwesterly veins or stringers are cut in the crosscut from the Chestnut to the Newman vein. Two of these veins intersect in the roof of the crosscut, and the northwesterly fissure faults the other about 3 inches, as shown in fig. 52.

About 8 feet west of the point where the crosscut enters the Newman vein, the latter is cut by a strong northwesterly lode (also visible in the crosscut) of barren crushed quartz. There is no recognizable faulting of the Newman vein.

Where crossed by the South Klingender cross vein, the Newman vein is pinched and splits up into stringers, but is not noticeably displaced. The northwesterly lode here consists of crushed quartz, and is about 2 inches wide.

Toward the northeast the Newman continues as a strong, fairly regular vein until it reaches the Cuarto cross vein. Within 4 or 5 feet of the latter, the Newman vein bends abruptly north and persists for about 15 feet along the foot wall of the Cuarto lode as crushed and dragged ore (fig. 53). It is commonly supposed that the Newman vein is offset at this point by faulting, which has effected a horizontal displacement of 90 feet, throwing the northeast portion of the Newman vein into line with the Klingender vein.

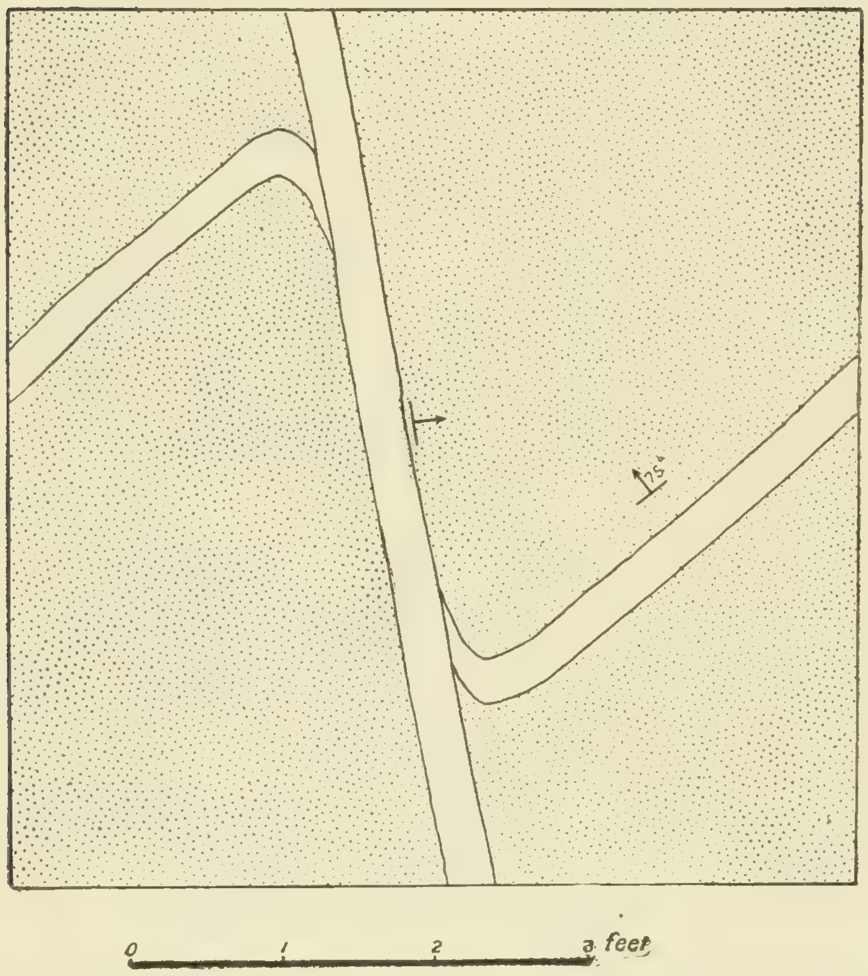


FIG. 54.—Plan of South Klingender vein faulted by the South Klingender cross vein.

This supposed continuation of the Newman vein is cut by the James cross vein, and is distinctly faulted, the northeast portion being offset about a foot to the northwest. This northwesterly fissure also faults the Newman No. 2 vein in the same manner, the offset in this case, however, being only about 6 inches.

Along the Klingender vein several small faults were noted along northwesterly fissures. The South Klingender cross vein faults the Klingender normally, offsetting the northeastern portion about 2 feet to the southeast.

The South Klingender vein is faulted by the South Klingender cross vein, as shown in plan in fig. 54. The northeasterly vein is curved and dragged to some extent along the fault plane.

In general it may be said that the demonstrable faults in the Newman mines are small in throw and normal in character.

RICO-ASPEN MINE.

Situation and development.—This mine is situated on the southwestern slope of Newman Hill, just north of Deadwood Gulch. As shown on Pl. XXXVI, its workings are contiguous to those of the Enterprise and Newman mines. Large amounts of rich ore were produced subsequent to the purchase of the mine by the present company in 1891. This ore was obtained chiefly from the veins and "contact" workings in the northern part of the mine in ground at that time in dispute between this company and the Enterprise Mining Company. Of late years but little ore has been shipped, and that has been mined by a few leasers. All of the old "contact" workings and a large proportion of the drifts are no longer accessible.

Country rock.—This is the same as that found in the Enterprise and Newman mines, including the persistent bed of blanket limestone. The general dip is from 10° to 15° to the southwest. Inspection of the geological map (Pl. XLI) shows that this is also the dip of the strata near the mouth of Deadwood Gulch, the direction of strike swinging around to the west in accordance with the main domical structure, of which the town of Rico occupies almost the central point.

Access to the workings was formerly gained through five shafts—the Aspen, Vestal, Jumbo, Montezuma, and Silver Glance shafts. The present adit is the Syndicate tunnel, nearly 3,000 feet in length. For 900 feet the tunnel has a southeast course. It then turns about S. 73° E. and continues on this course to the face, which could not be reached in 1900 on account of the presence of gas. The Stephanite tunnel, which enters the hill just north of Deadwood Gulch, has a course of N. 72° E. for about 700 feet, and connects with drifts and crosscuts from the Syndicate tunnel. It is now caved in. The Syndicate tunnel is only a short distance below the blanket which comes down to this level at the Silver Glance shaft, a short distance south.

The lodes.—Owing to the condition of the workings no satisfactory study could be made of the lodes in the Rico-Aspen mine. They are for the most part, however, direct continuations of those worked in the Enterprise mine, and are of similar character. The Syndicate vein is the same as that known as the Stephens, farther northeast, and as the Eureka in the Enterprise ground. The Jumbo No. 2 appears to correspond with the Jumbo No. 2 in the Enterprise, and the Star is probably the Jumbo No. 3. The latter may, however, be represented by the Selenide vein. The exact relations of the Jumbo, Montezuma, and so-called Montezuma-Jumbo veins could not be ascertained.

The Selenide vein, which was being worked by leasers in 1900, has an average width of less than 6 inches and is usually frozen to the walls. It has a dip of about 85° to the northwest. It is filled with banded ore in every way similar to that already described in the northeasterly veins of the Enterprise mine.

As a rule, and excepting the disputed territory on the northeast, the veins are smaller and not as rich as in the Enterprise workings.

Northwesterly lodes are numerous in the Rico-Aspen workings, and many of them are well exposed in the Silver Glance drift, which connects the shaft of that name with the Syndicate tunnel. These, as elsewhere in Newman Hill, are filled with barren white quartz, showing more or less crushing. They are generally accompanied by slight normal faulting, the maximum displacement observed being about 5 feet.

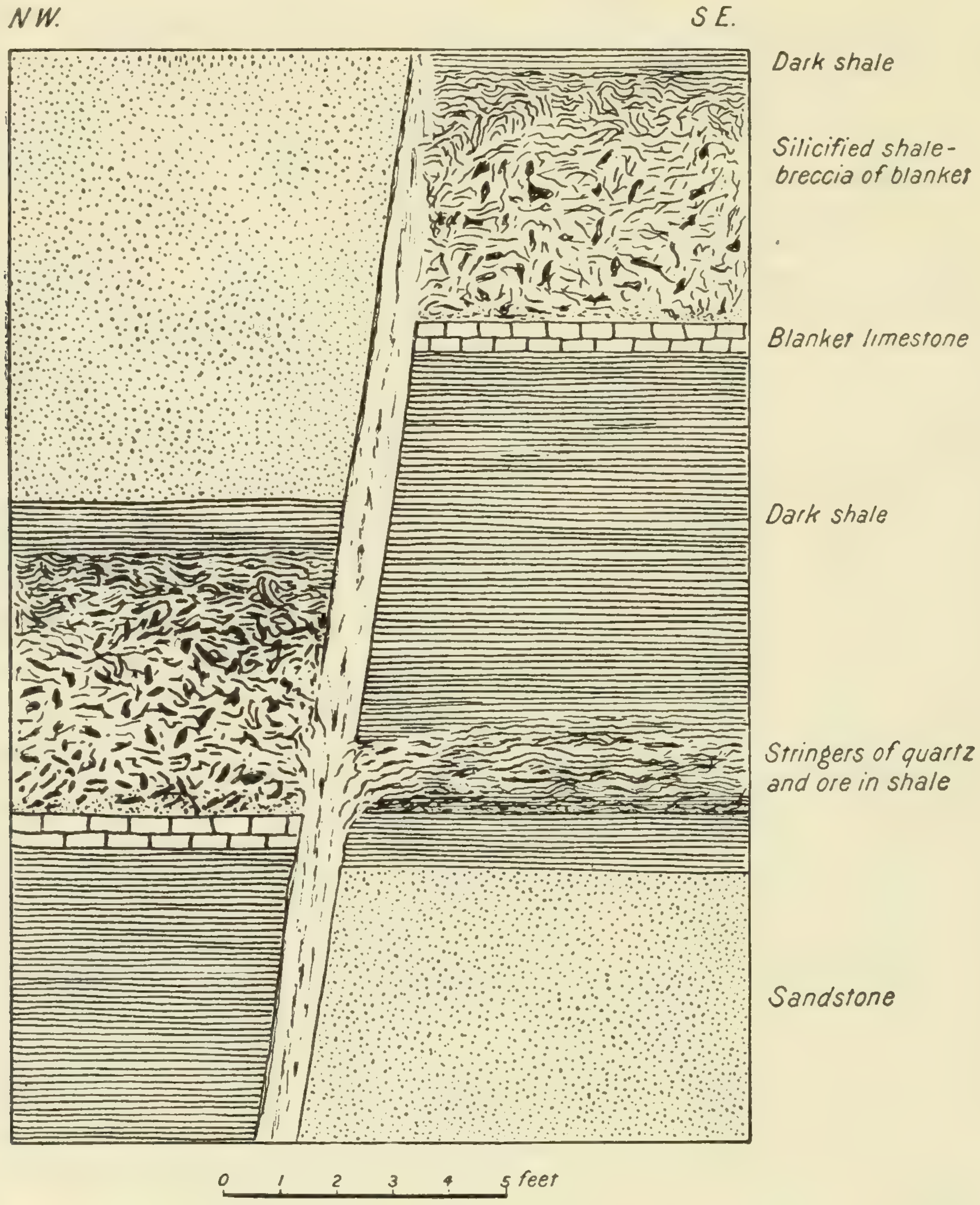

N.W.
S.E.
Dark shale
Silicified shale-breccia of blanket
Blanket limestone
Dark shale
Stringers of quartz and ore in shale
Sandstone
0 1 2 3 4 5 feet

FIG. 55.—Diagrammatic section through the Montezuma vein, showing faulting of blanket and occurrence of a second ore-bearing horizon below the blanket limestone.

The blanket.—But little of this can now be seen in the mine, but the portions visible are of considerable interest. Above the Montezuma vein, just north of the Syndicate tunnel, the blanket is reached at 60 feet above this level. It resembles closely that described in the Enterprise mine, but is here subject to more sudden rolls and changes of dip. In places it has also undergone considerable differential movement, as shown by very irregular slip planes traversing the soft shale breccia. These are particularly abundant in the upper portion of the blanket, just below the less disturbed black shales forming the roof. The general dip of the blanket is southwest at from 10° to 20°.

Near this point the Montezuma vein is cut by two northwesterly veins. The southern one faults the Montezuma, offsetting the northeast part of this vein a few feet to the southeast. Above the intersections of these veins the dark shale breccia has been beautifully silicified by white quartz. All the finer material of the breccia has been replaced by pure white quartz, while the larger fragments, partly silicified, persist as more or less shadowy dark mottlings in a dazzling white matrix. No ore was seen in the blanket at this point.

The Montezuma vein (or a spur from it) faults the blanket above it as shown in fig. 55. The dislocation is normal, and the vertical displacement is about 8 feet. A portion of the vein turns off flatly into a bed of shale below the stratum of blanket limestone, and has formed a nearly horizontal bunch of stringers and some ore, constituting a local ore horizon below the main blanket (see fig. 55).

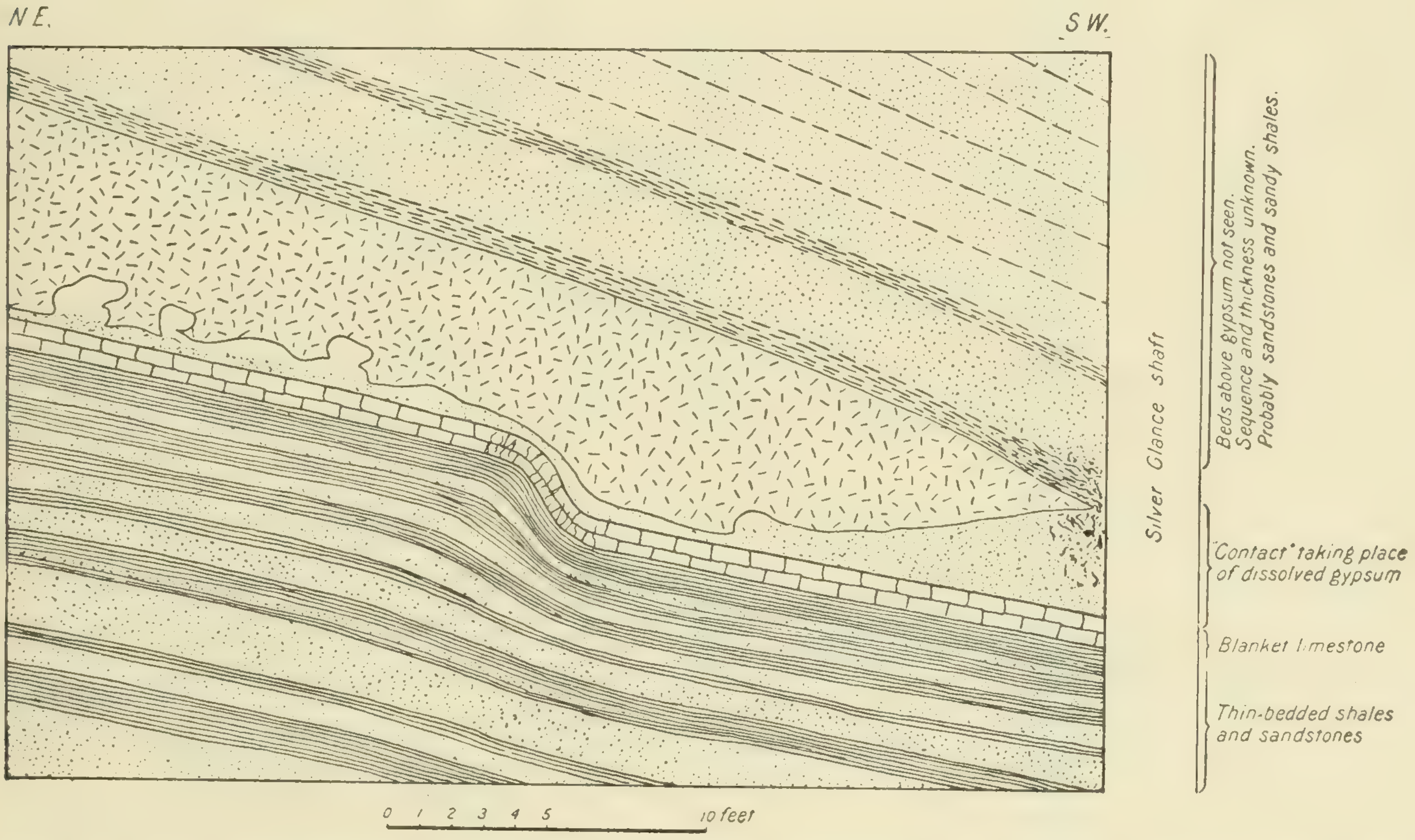

NE.
SW.
Silver Glance shaft
Beds above gypsum not seen. Sequence and thickness unknown. Probably sandstones and sandy shales.
"Contact" taking place of dissolved gypsum
Blanket limestone
Thin-bedded shales and sandstones
0 1 2 3 4 5 10 feet

FIG. 56.—Partly diagrammatic sketch of the gypsum "contact" and inclosing beds at the Silver Glance shaft, Rico-Aspen mine.

In the vicinity of the Silver Glance shaft large masses of gypsum, occupying the stratigraphic position of the blanket, are well exposed, and excellent sections of the rocks immediately underlying the blanket horizon are obtainable in the Selenide drift near this shaft.

The gypsum forms a solid, massive, crystalline bed, the maximum thickness of which is unknown, but which is probably considerably over 6 feet. When drifts are run under this gypsum, the underlying thin-bedded shales, sandstones, and limestone cave away up to the gypsum, leaving the under surface of the latter as a solid roof. As a rule this surface is very even and dips to the south at about 25°.

Wherever it presents such regularity it rests directly upon the blanket limestone with no trace of the usual blanket elsewhere found at this horizon. In such cases there is no ore found.

But the under surface of the gypsum is not always even. It is sometimes irregularly corroded or dissolved away so that it becomes pitted with rounded cavities, up to 8 feet in diameter, resembling inverted potholes. Groups of these cavities are shown in Pls. XXXII and XXXIII, *A*, which are from photographs taken just north of the Silver Glance shaft, and a section across such a group is shown in fig. 56. When such cavities are first opened they are reported to be usually partly filled with loose, spongy "gypsum." Wherever the gypsum shows no solution it rests snugly upon the blanket limestone with a perfectly sharp and tight bedding contact. But wherever solution has attacked the underside of the gypsum, more or less of the gray pulverulent material, already described as a characteristic feature of the bottom of the "contact" in the Enterprise mine, always lies upon the limestone (see fig. 56).

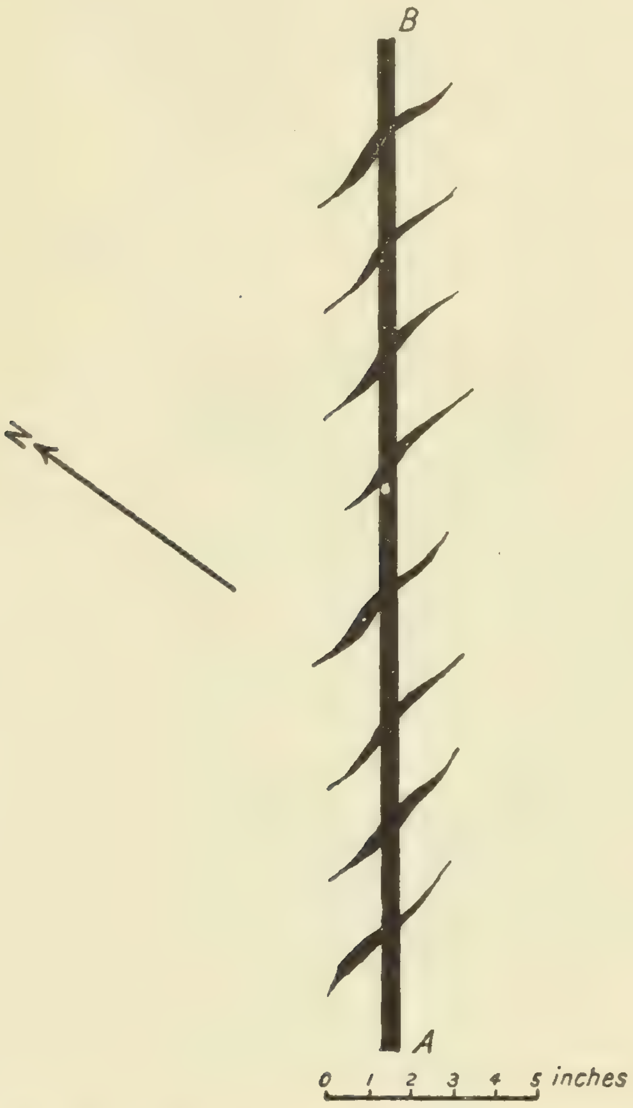


FIG. 57.—Plan of small gash viens produced on underside of gypsum by the dying out of a stringer, which appears a few inches below as the straight veinlet A-B.

Toward the south the gypsum thins out and disappears at the Silver Glance shaft, where its place is taken by the usual silty "contact" material up to 4 feet in thickness, grading above into a breccia of shale and sandstone. This thinning and final disappearance is undoubtedly the result of the removal of the gypsum by solution. The general relations of the gypsum to the blanket and to the inclosing beds are shown in fig. 56, which is a sketch of the side of the Silver Glance drift just northeast of the shaft.

The thin-bedded sandstones and shales which underlie the persistent bed of blanket limestone are well exposed at the point of the above sketch and also in the Selenide drift near by. In this drift the splitting up of individual beds of sandstone or shale 3 or 4 inches thick into several thinner beds and the frequent complete wedging out of the latter can be plainly seen. These very thin beds, particularly the shales, are frequently locally distorted and even thrown into small overturned folds, although more massive beds above and below them are not noticeably disturbed. It is but a step from such a deformed bed of shale to the production of a shale breccia identical with some of the so-called "contacts" of this region. The bed of limestone immediately beneath the gypsum is without much doubt the same as the bed underlying the blanket in the Enterprise mine. In this portion of the Rico-Aspen workings, however, there is a second very similar bed, stratigraphically a few feet below it.

Near the Silver Glance shaft the Selenide drift is so close to the blanket horizon that the Selenide vein does not appear as a simple vein, but is split up into a multitude of small stringers of white quartz. Some northwesterly veins which occur at this point exhibit similar behavior. These stringers are usually less than 1 inch in width and are very numerous. They show a general tendency toward parallelism with a course of N. 55° E. They all die out at or before reaching the bottom of the bed of gypsum. Many are mere gash veinlets, dying out above and below in the thin fissile beds below the blanket limestone. Stringers which reach the bottom of the gypsum, or rather a thin shaly skin adherent to its under surface, frequently split at the point of disappearance into a curious linear system of gashes, represented in fig. 57. One or two stringers were noted passing up into the silty blanket material which underlies the corroded gypsum, as if they were of later date than the formation or deposition of this substance.

South of the Silver Glance shaft the blanket can no longer be reached. All accounts agree that it contained ore and that it acquired in that direction a steeper southerly dip. At or near the line where the geological mapping indicates the existence of the Deadwood fault the blanket and its ore grew thinner and suddenly turned down with a steep dip to the south, so that it could no longer be followed without sinking.

LEXINGTON TUNNEL.

This tunnel was driven at a cost of $64,000 to undercut the workings of the Newman and Enterprise mines. It has a straight course of S. 75° E., and a length of 3,000 feet. It cuts the Newman Hill lode systems about 350 feet below the lowest level of the Enterprise, and has a connection with these upper workings through the old Jumbo shaft, about 70 feet north of the tunnel and about 1,900 feet from its mouth. This shaft is 950 feet deep and extends 65 feet below the Lexington tunnel. According to Mr. Charles Newman, its bottom is in porphyry, immediately above which is some soft, broken shale, constituting a kind of "contact."

The Lexington tunnel is mainly in massive sandstone of the Lower Hermosa, with subordinate lodes of shale. The general dip is S. 35° W. at from 10° to 15°. Several veins are cut belonging to the northeasterly and northwesterly systems, but at this depth they are all small and relatively barren. The breast of the tunnel could not be reached by about 500 feet, but no vein was observed over 6 inches in width, and none which carried workable ore. The Eureka-Stephens syndicate vein crosses the tunnel about 75 feet west of the crosscut connecting with the Jumbo shaft. A few feet west of the vein a dike about 15 inches in width was cut. Its course is about northeast and southwest, and it dips west at 75°. The rock is much decomposed, but appears to be a fine-grained diabase, distinctly different from the usual gray monzonite-porphyry, common as intrusive masses in the Lower Hermosa sediments. This is perhaps the same dike noted by Farish in the Enterprise mine.

No ore has been taken from the Lexington tunnel. It affords, however, a starting point for prospecting farther eastward, under Dolores Mountain, than is possible from the Group tunnel, which, on account of the general southeasterly dip of the strata, can not be continued much farther without cutting through and coming out above the Enterprise blanket. The indications for the existence in this direction of profitable bodies of blanket ore, and productive veins yet undiscovered, are not altogether encouraging. Yet it is difficult to find a good reason for driving the Lexington tunnel thus far, unless it was intended to carry it farther.

GOLDEN FLEECE OR NEW YEAR MINE.

This mine, which is not at present of great economic importance, is yet of considerable interest. It lies at an elevation of about 9,050 feet on the west slope of Newman Hill, near the southeast corner of the town of Rico. It is entered by an adit tunnel about 200 feet below the Group tunnel, and, although from 50 to 100 feet higher than the Lexington tunnel, this adit penetrates beds stratigraphically lower than those seen in the latter.

The tunnel enters in porphyry, apparently near the upper part of the thick sheet of monzonite-porphyry mapped by Cross and Spencer, and by them described as intrusive into the Lower Hermosa sediments and attaining a thickness of 500 feet. It is without much doubt a portion of the same mass in which the Skeptical shaft is sunk, which is reached in the bottom of the Jumbo shaft, 65 feet below the Lexington tunnel, and which is encountered in the diamond drill hole driven from the floor of the Syndicate tunnel.

The tunnel, from the mouth in, follows a vein in the porphyry for several hundred feet. This vein strikes about N. 75° E. and is practically vertical. It is usually simple, about 6 inches wide, and is frozen to its porphyry walls; but it sometimes divides into tight stringers. It carries sphalerite, galena, and pyrite, and is low in grade. Above this vein, and resting upon the upper surface of the porphyry sheet, which dips to the south, is a "contact" carrying some ore. At the point first seen, this blanket is about 5 feet thick. At its bottom, resting upon the porphyry, is about 8 inches of crushed quartz containing sulphides—chiefly pyrite. Above this is 18 inches of soft shale breccia, then about 6 inches of disturbed black or dark-gray shale. Above this rests 2 to 3 feet of soft, gray, somewhat calcareous shales, which are crushed and disturbed and sometimes reduced to a gray clay. The top of the blanket was not visible at this point. The fragments of shale are usually impregnated with fine pyrite. There is not always a sharp line between the dark and light shales and the latter are, in part at least, bleached and altered forms of the former.

Above veins which enter it from below, the blanket breccia is frequently cemented and silicified by quartz carrying pyrite. In such cases the shale fragments can be recognized merely as siliceous blotches, of uncertain outline, surrounded by white quartz.

In the southern part of the workings the porphyry sheet can be seen dipping down at about 30° in a direction S. 25° E. Its contact with the shales is plainly an eruptive one, although the sheet in general follows the bedding planes. The blanket breccia does not always rest directly upon the porphyry, but is sometimes separated by a varying thickness of shale.

The blanket ore, of which not much was seen, consists chiefly of chalcopyrite, pyrite, galena, and sphalerite in a somewhat spongy quartz gangue. It is entirely different in character and much lower in grade than the ore of the Enterprise blanket, from which it is separated by fully 400 feet of strata. The two contacts are different, not only in character, but probably in origin.

UNION-CARBONATE MINE.

Situation.—Perched at an altitude of 10,400 feet on the northwest spur of Dolores Mountain, the shaft house of this mine is easily seen, on looking due east from Rico, as the highest of the mine buildings that dot Newman Hill. It lies just a mile east of the town in a straight line, but is reached by a road which zigzags up the slope of Newman Hill and passes over into Allyn Gulch.

History.—Work on the mine began in 1879, when two tunnels run in from the hillside struck the same ore body, and litigation followed. From 1880 to 1887 the mine lay idle. Then after spending some $25,000 at law, the contestants agreed to work the mine together. Operations were resumed, and ore was extracted until 1894. The total product has been about $100,000, although the workings are more extensive than in many mines which have produced several times that amount.

Development.—The mine is opened by a shaft 356 feet deep, and by three tunnels connecting with the shaft on two main levels at 190 feet and 210 feet below its collar. A rough sketch map of the principal workings (based on hand-compass readings and pacing) is shown in fig. 58.

A fourth tunnel, known as the Fickle Goddess tunnel, has been run in from the side of Newman Hill, on a course N. 83° W. for a distance of 682 feet. This is intended to connect with the deepened Union-Carbonate shaft about 800 feet below its collar.

Country rock.—This is in general the same as in the Enterprise sandstones and shales of the Lower Hermosa, with an occasional bed of limestone. The general dip is southeast or east at 10° to 15°. These beds are cut by sheets and dikes of monzonite-porphyry. The sheet-like intrusions are more numerous than in the mines farther south, and appear to have directly influenced the ore deposition. Although the workings in all probability pass through the same stratigraphic horizons that are encountered in the Enterprise, Newman, and Rico-Aspen mines, yet the characteristic blanket of these mines, with its underlying blanket limestone, overlying shales, and included masses of gypsum, can not be identified in the Union-Carbonate, where ore deposition took place under different conditions.

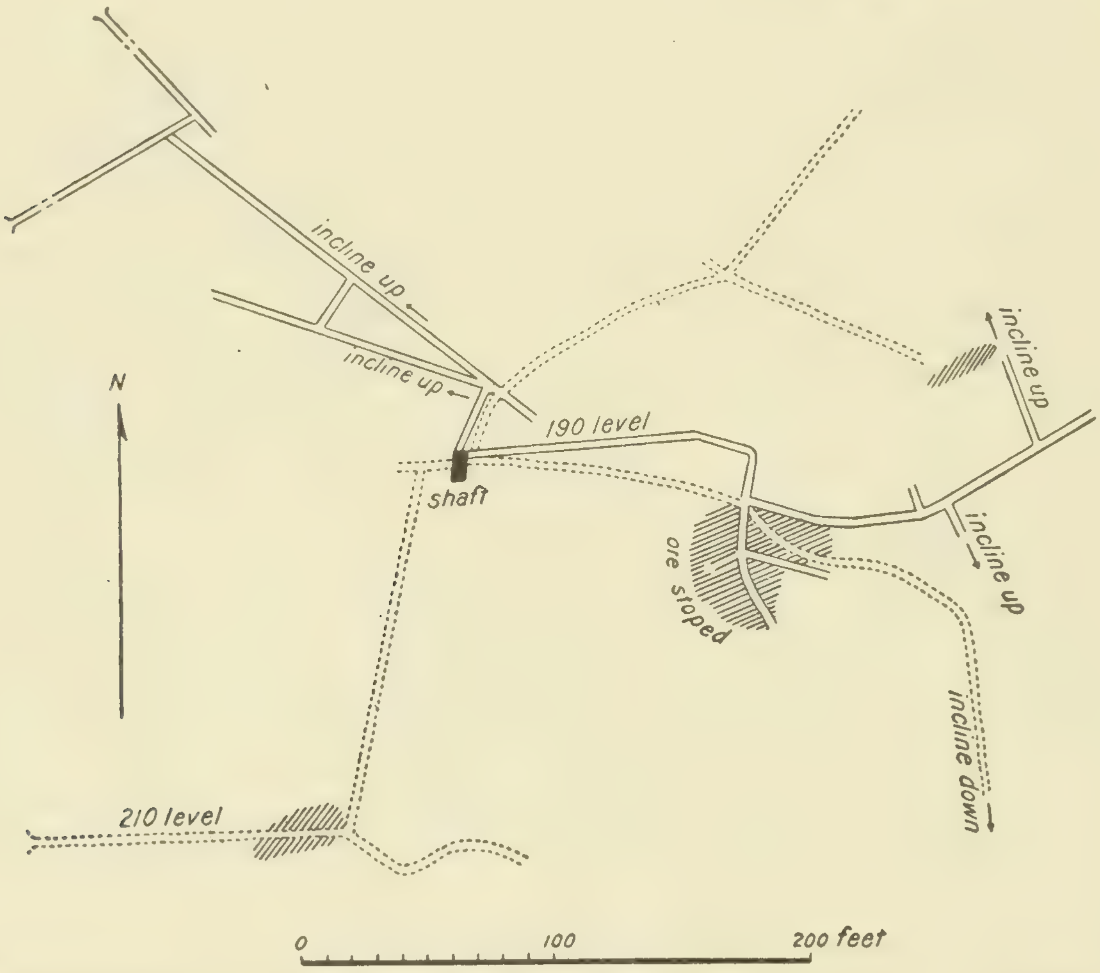


FIG. 58.—Sketch plan of the principal workings of the Union-Carbonate mine.

Occurrence of the ore.—The country rock of the Union-Carbonate mine is traversed by numerous vertical veins, which show but few points of resemblance to those seen in the Enterprise mine and in the southern part of Newman Hill. A few fissures have a nearly north-

and-south course, but these are relatively unimportant. By far the greater number strike from N. 60° W. to N. 75° W. It will be remembered that the northwesterly fissures of the Enterprise and neighboring mines rarely depart more than 45° from a north-south course, the divergence usually being only a few degrees. The prominent veins of the Union-Carbonate, however, are much more nearly east and west than north and south. It is doubtful whether they can be considered as belonging to the same system as the northwesterly fissures previously described. The northeasterly veins of the Enterprise, Newman, and Rico-Aspen mines, were not recognized in the Union-Carbonate workings at all. If they occur, it is as insignificant stringers of no known importance. In the Fickle Goddess tunnel, however, 682 feet below and to the west of the collar of the Union-Carbonate shaft, several northeasterly veins are cut, but they do not resemble those in the Enterprise ground, and carry little save quartz and low-grade pyrite, resembling the northwesterly rather than the northeasterly lodes of the Enterprise.

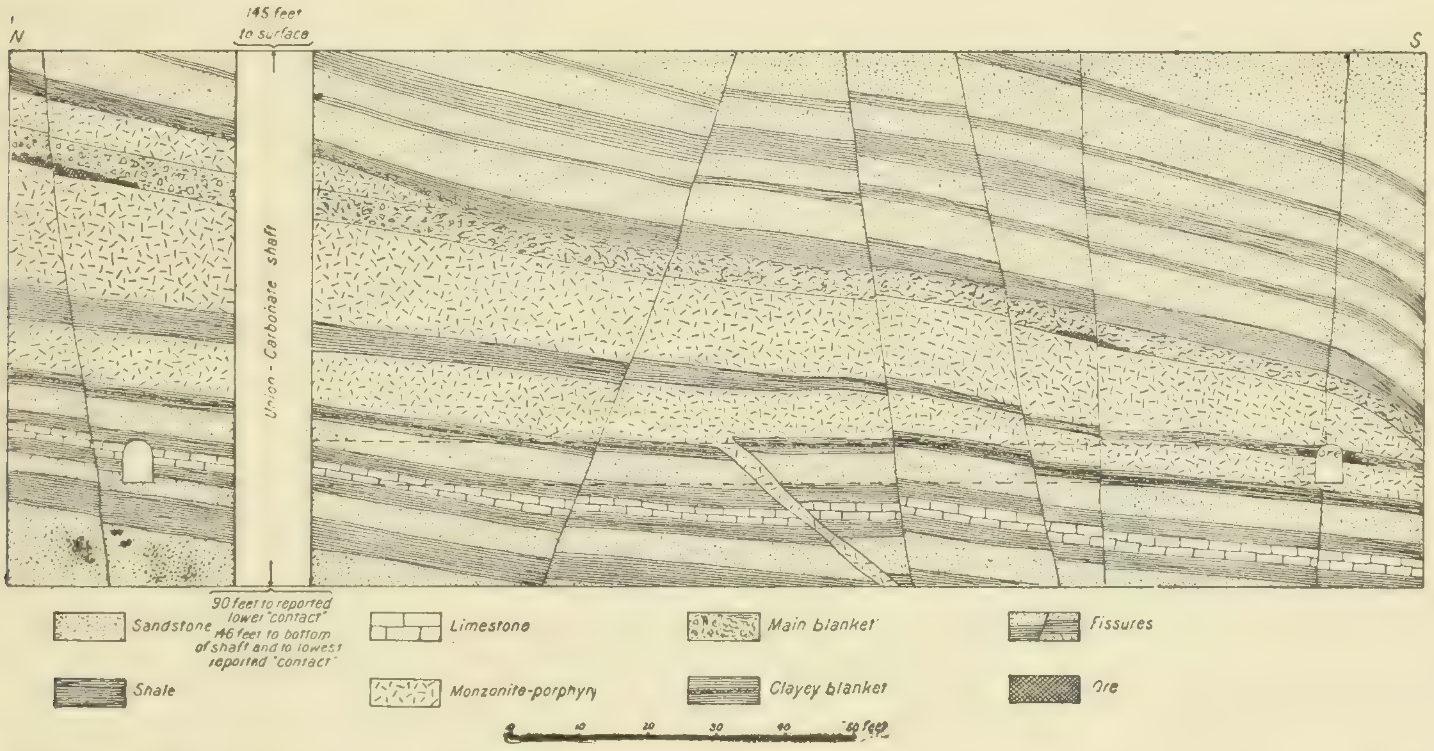


FIG. 59.—Diagrammatic north-south section through the Union-Carbonate mine, illustrating the general structure of the country rock, and showing some of the northwesterly fissures and their relation to the blankets and ore bodies.

All of the veins seen are small. They are sometimes composed of quartz carrying a little pyrite or low-grade galena ore. Frequently this quartz is crushed and the vein is often nothing more than a fissure filled with a little crushed country rock, broken quartz, and gouge.

These fissures are usually fault planes, but the displacement is rarely more than a few inches, and is usually normal. Several such faults can be well studied in the crosscut south of the shaft on the 210-foot level, and some of them are indicated in the general section of fig. 59. One vertical vein with a nearly east-west strike, followed for some distance by the main drift on the 190-foot level, is connected with a vertical displacement of the country rock amounting to about 5 feet.

The rocks on the south have been dropped relative to those on the north.

As a rule, the veins in the Union-Carbonate mine carry no workable ore. This is found only in so-called "contacts" near their intersection by the vein fissures. An exception to this statement must be made in the case of one important vein striking N. 65° W., and dipping southwest at 85°, which carried ore to a depth of 30 or 40 feet below the main blanket horizon. Some of the largest and richest bodies of blanket ore occurred above this fissure.

There are several so-called "contacts" in the mine, and as they differ in character, they will be separately described.

The principal ore-bearing blanket passes through the shaft a few feet above the 190-foot level, but is cut by the latter in the southeastern portion of the workings, owing to the general southeasterly dip of the inclosing rocks. In the extreme southern portion of the mine the dip rapidly increases up to 60°, and carries the contact below the 210-foot level. This "contact" is generally 4 or 5 feet in thickness, and rests upon an intrusive sheet of porphyry. In the northern part of the mine it is overlain also by porphyry, but the latter sheet thins out toward the south and east, and the blanket is there overlain by shale. There is considerable irregularity in these relations, however, and it is not uncommon to find the porphyry roof suddenly giving place to shale, or vice versa.

In its less altered condition the blanket is a breccia of somewhat mineralized fragments of shale and porphyry. Where the roof is shale the particles of this rock predominate, even to the exclusion of the porphyry, and the breccia presents the appearance shown in Pl. XXXIV, *B*, which is from a photograph taken on the downward incline on the southeast corner of the 210-foot level. The blanket material at this point consists of angular fragments of gray calcareous shale embedded in a gray clay apparently derived from the disintegration of the shale. Some of these fragments are as much as a foot cube, and in the bottom of the breccia lie in all attitudes. Near the top, however, they remain with their planes of bedding more nearly parallel, and pass with no sharp break into the less-disturbed shales of the roof (Pl. XXXIV, *B*). All of the shale fragments show more or less alteration. Many are bleached nearly white and effervesce freely with dilute acid, whereas the darker fragments contain less calcite. Accompanying the change in color, there has been some replacement of the shale by pyrite, which tends to form in thin sheets parallel to the general laminations of the shale. In some cases, however, a bed of the shale three-quarters of an inch or more in thickness may be observed almost entirely replaced by quartz and pyrite. A characteristic feature of such replacement is the formation of little vug-like cavities partly filled with porous quartz and a resultant porous, friable structure in the whole replacing aggregate. Fig. 60 is a drawing, actual size, of such a replaced band of shale, which a few feet away is only slightly mineralized and preserves its shaly structure. At least a part of the movement which produced the brecciation is later than this mineralization

Above the 190-foot level, where the blanket lies between two sheets of porphyry, and particularly above the more prominent northwest veins, the breccia has been vigorously altered. In some places it is a solid body, 5 feet in thickness, of white quartz and pyrite. Sometimes the latter predominates in crumbling masses containing bunches of galena ore. At other times the quartz has a porous, honeycombed structure containing pyrite and free sulphur. In some such cases the pyrite seems to have been partly dissolved and carried away without deposition of any residual oxides of iron. In others the porous structure has plainly resulted directly from the metasomatic replacement of fragments of porphyry by quartz and pyrite, with the removal of some of the constituents of the rock. Frequently the blanket quartz is crushed to a white powder—" sugar quartz."

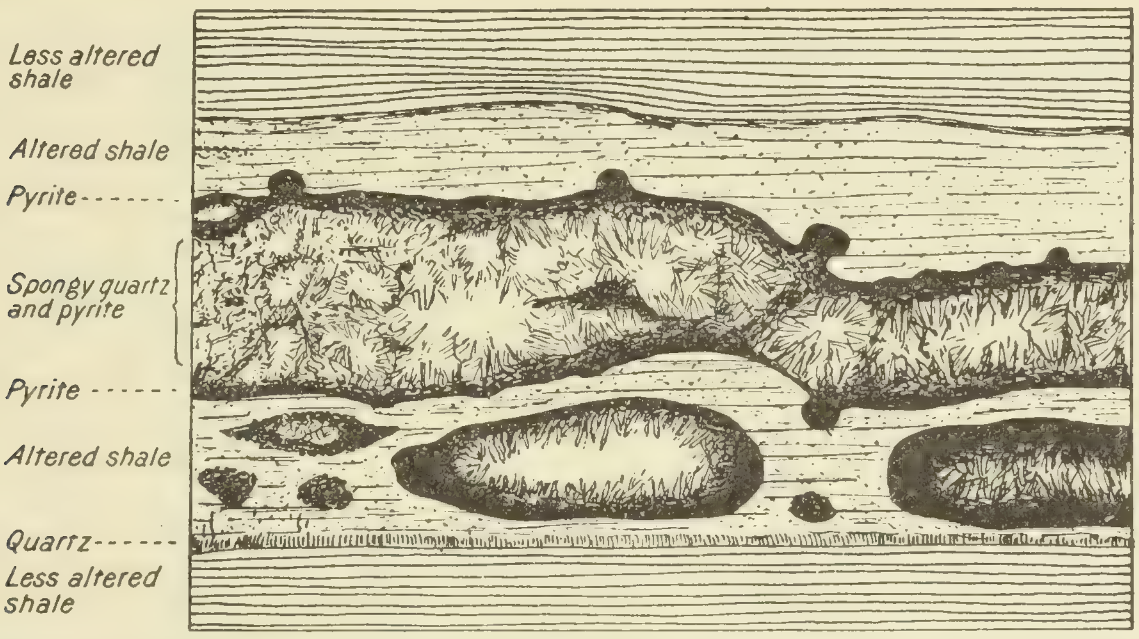


FIG. 60.—Replacement of a layer of shale by pyrite (black) and spongy quartz, showing characteristic small vugs with outer shells of pyrite and inner lining of quartz crystals.

The masses of quartz and low-grade ore just described have resulted from the replacement of a breccia of porphyry and shale by quartz and ore. Where the process has not been so complete, fragments of porphyry may still be detected in the silicified mass. There were at least two steps to the process, the quartz of an earlier generation having been shattered and recemented by later deposition.

However this blanket breccia may have been produced, it has certainly been to some considerable degree a plane of faulting, the beds above it having moved relatively to those below it. But the extent and direction of this movement are wholly unknown. The exact behavior of the vertical veins to this bedding fault could not be ascertained. They apparently do not split up into stringers on approaching the blanket, as do the veins in the Enterprise. They probably pass upward through it, suffering more or less displacement.

Below this principal blanket occur several others of less extent and importance and of different character. These occur in beds of dark shale, particularly in thin beds lying between beds of sandstone or sheets of porphyry. When fully developed these blankets consist of unctuous yellow clay, usually finely banded parallel to the general bedding of the rocks between which it lies. This clay is an alteration product of the shale, and the banding is the result of the original shaly lamination. The various steps in the change from shale to yellow clay may be well seen in the crosscut running south from the shaft on the 210-foot level.

In the vicinity of some of the vertical fissures these clay blankets sometimes contain bunches of ore, usually in the form of impure argentiferous lead carbonates, with occasionally some residual galena. Such an ore body was stoped out from the southern adit tunnel on the 210-foot level. It extended for about 4 feet into the blanket on each side of a vertical fissure striking N. 75° W., and averaged about 3 feet in thickness. In this case footwall and roof were both of porphyry. In the neighborhood of the shaft this shale bed, in part altered to clay and occasionally carrying a little ore, is probably about 30 feet below the main blanket previously described. In the southern part of the workings they come closer together. There has been no faulting along this lower blanket horizon, as shown by the continuity of a dike of porphyry which connects with an overlying intrusive sheet (see fig. 59, p. 343). The shale has been changed to clay in situ by chemical processes, unaided by attrition.

Blankets similar to the last, often of very local extent, were noted at other stratigraphic horizons. Still other blankets are said to exist at 300 and 356 feet below the collar of the shaft, but they could not be reached in 1900.

The ore shipped from the main blanket of the Union-Carbonate mine averaged about $20 per ton as prices were then, and was therefore of low grade compared with the Enterprise or Rico-Aspen ore. It is said to have been 7 feet thick in places, and could be easily mined. It contained about 0.1 ounce of gold, 12 ounces of silver, and a varying amount of lead.

FOREST-PAYROLL MINE.

Situation.—This mine is on the same spur of Dolores Mountain as the Union-Carbonate, but lies on the side toward Allyn Gulch, with its principal adit at about 10,150 feet elevation.

Development.—The principal workings are reached through the Payroll tunnel, about 400 feet in length, running S. 32° W. This tunnel connects with drifts, winzes, and stopes, on two nearly parallel veins, and with irregular workings in two "contacts" or blankets, lying one above the other. There are in addition 5 or 6 other tunnels run into the hillside at higher elevations.

Country rock.—This is the Lower Hermosa, consisting of shales, sandstones, and limestones. It is cut by some large dikes of monzonite-porphyry, which are connected with intrusive sheets of the same rock.

The lodes.—Several fissures are cut by the Payroll tunnel, but none of them have proved economically important. The Magpie vein, intersected about 50 feet from the tunnel mouth, strikes N. 60° W. and dips 80° N. It is little more than a fissured zone in porphyry, containing some gouge.

About 300 feet from the mouth the tunnel cuts the main Forest-Payroll lode, which has been drifted on for 500 or 600 feet. It strikes about N. 75° W. and dips about 85° SW. The lode shows a maximum width of about a foot of quartz and low-grade ore, containing much sphalerite. It is usually frozen to the southern wall, but on the northern wall shows some gouge and crushed country rock. Just within this wall is a small parallel vein of white, barren quartz, 3 or 4 inches wide, which appears to be of later age.

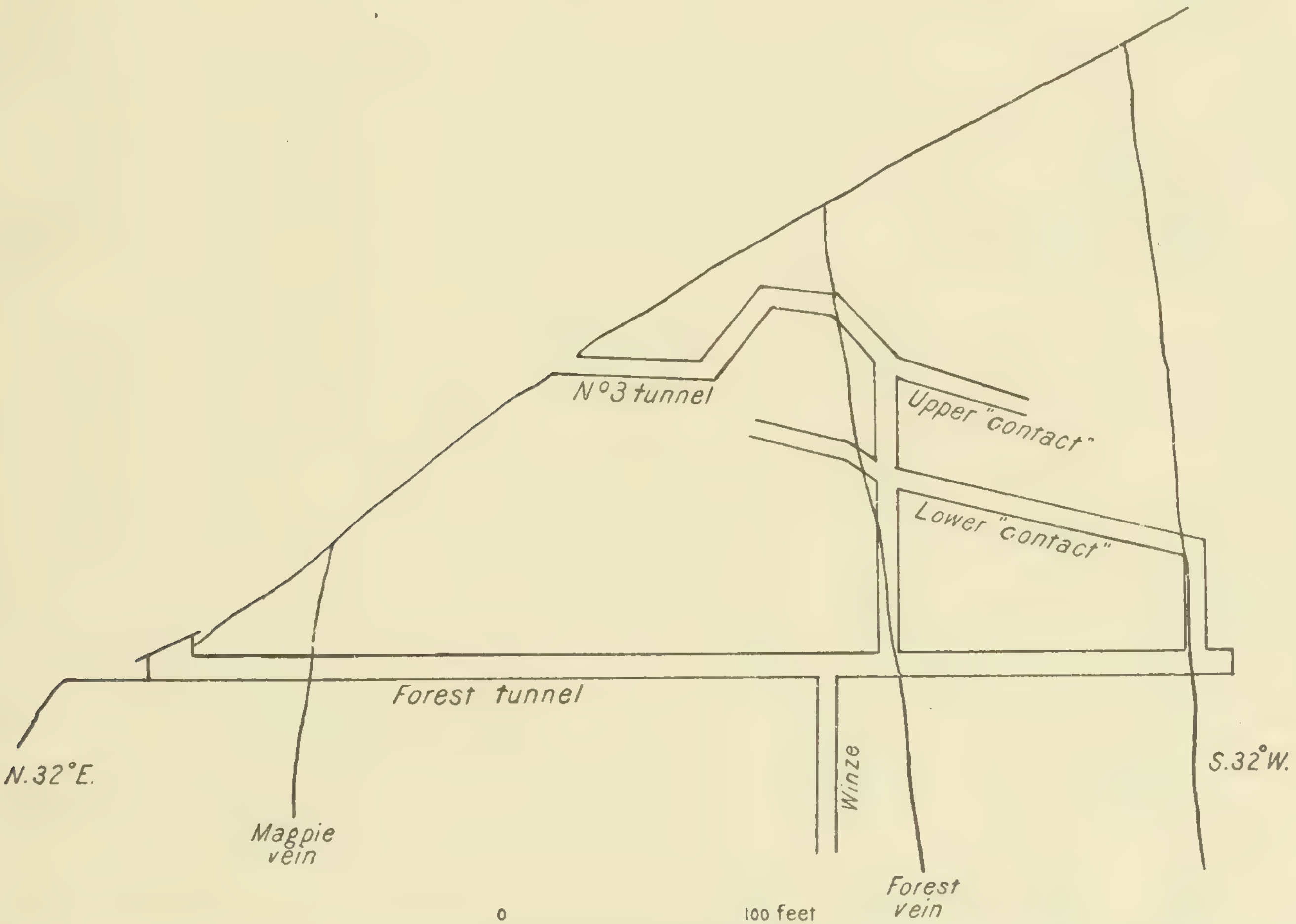


FIG. 61.—Vertical sketch section through the Forest-Payroll mine, along line of main tunnel.

A third vein is cut near the breast of the tunnel. This is parallel to the main lode, but is small and has been drifted on for only a few feet.

The ore in the Forest vein is low grade and is found only in small bunches.

The blankets.—The lower of the two blankets ("contacts") lies about 85 feet above the main Forest drift. It is about 5 feet in thickness and dips S. 15° E. at angles from 10 to 15 degrees (fig. 61). It is a breccia of shale mixed with yellow clay and resembles some of the blankets of the Union-Carbonate mine. The roof is shale, while the floor is sandstone. The blanket is not everywhere reduced to breccia and clay for its full thickness, but the softer materials are sometimes separated by harder beds of shale or sandstone which have resisted the transformation undergone by the more susceptible beds and preserve their firmness and continuity. The various nearly vertical fissures encountered in the drifts and crosscuts below pass upward through the blanket and fault it. The maximum throw observed is about 15 feet, due to the Payroll vein. The result of the faulting is to cause the blanket to descend by a series of steps toward the south.

Ore occurs in the blanket in the immediate vicinity of the vertical fissures, but it is small in amount and of low grade. It is sometimes accompanied by crushed white quartz, and is often in the form of impure argentiferous lead carbonate. Some galena occurs, however.

The upper blanket lies from 30 to 50 feet above the lower, the two being generally parallel. It is 5 or 6 feet in thickness, being somewhat larger than the lower one. The roof is shale, rather disturbed and broken, while the floor is sometimes the upper surface of a sheet of porphyry, sometimes a shaly calcareous sandstone.

The blanket material is similar in general appearance to that described in the lower blanket, but it contains considerable amounts of soft, unctuous, black material, which dries to a sooty powder. This substance, which, as shown by chemical analyses (p. 283), is largely oxide of manganese, is frequently in direct association with masses of limestone, the occurrence of which in the blanket is of much interest. In some portions of the workings the limestone occupies the entire depth of the blanket zone, extending from the porphyry or sandstone floor up to the shale roof. It is often fissured and broken, the crevices being filled with the black material above referred to. In other portions the limestone is absent, or occurs in isolated masses of irregular shape, coated with the black substance and embedded in the soft blanket material.

The limestone is finely granular in texture, light buff in color, and is apparently far from being pure calcium carbonate. It is minutely laminated parallel to the general bedding of the inclosing sediments. The black, sooty substance is plainly an alteration product or residue of this limestone. It penetrates the latter irregularly and works inward along the laminæ from the surface most exposed to the attack of the solutions which have effected the transformation. It is apparent that the relation of this limestone to the upper Forest-Payroll blanket is closely analogous to that of the gypsum to the Enterprise and Rico-Aspen blanket.

The upper blanket is faulted by the nearly vertical northwest fissures in the same manner as the lower one. The fissures are sometimes filled with a tough clay gouge, showing evidence of recent movement.

The ore of the upper blanket consists mainly of galena in various stages of alteration to cerussite and anglesite. It occurs in relatively small bodies alongside the vertical fissures. It is not known to occur in the limestone as a direct replacement.

The product of the mine is not known, but can scarcely have exceeded a few thousand dollars.

OTHER MINES.

Mediterranean tunnel.—This is on the south side of Allyn Gulch, at an elevation of about 9,800 feet. It runs in a southerly direction and has a length of about 1,500 feet. The country rock is the Lower Hermosa series of sandstones and shales, cut by several dikes and intruded sheets of monzonite-porphyry.

Owing to the gas in it, this tunnel could not be entered in 1900, but G. W. Tower, who examined the workings in 1898, has recorded the following section, measured northward from the breast of the tunnel out:

69 feet. Massive grits. Strike N. 60° W. Dip SW. 20°.
45 feet. Porphyry dike. Strike N. 60°. W. Vertical.
30 feet. Mineralized sediments.
00 foot. Barren fissure. Strike N. 55° E. Vertical.
45 feet. Porphyry. Strike N. 60° W. Vertical.
30 feet. Dark shale. Over this shale is a flat ore body. Strike N. 70° W. Dip SW. 10°.
84 feet. Massive, dark, hardened shale. In places the shale is impregnated with pyrite and chalcopyrite.
12 feet. Porphyry, dipping south and crossing the beds, 9 feet.
18 feet. In sediments to 6-inch vein. Strike E.–W. Vertical. Zinc and lead.
56 feet. Shales, to porphyry. Strike N. 70° E. Vertical.
12 feet. Porphyry. Strike N. 55° W. Vertical.
39 feet. Shales and sandstones. One small vein of quartz. Strike N. 75° W. This turns into the bedding planes of the strata and shows both vertical and horizontal movement.
00 foot. Narrow dike. Strike E.–W. Vertical.
12 feet. Grits, to fissure. Strike N. 60° W. Vertical, 1-inch fissure. The walls are coated with quartz and pyrite. There is also some impregnation of the adjoining country rock.
17 feet. Grits and shales, to fissure. Strike N. 57° W. Dip SW. 50°.
1 foot. Porphyry dike.
17 feet. Shales and sandstones, to mineralized fissure. Strike N. 70° E. Vertical. Eight inches of clay, cubical pyrite, and quartz.
21 feet. Impregnated grits, to fissure. Strike N. 55° W. Vertical.
18 feet. Porphyry.
00 foot. Mineralized fissure. Strike N. 83° W. Vertical. Breccia, containing pyrite and chalcopyrite; 3 feet wide.
32 feet. Sedimentaries.
18 feet. Porphyry dike. Strike N. 78° W. Crosses stratification at low angle.
6 feet. Grits, to vein. Strike N. 53° W. Vertical.

11 feet. Massive pyrite. Strike N. 70° W. Vertical. Crystals, 1 to 2 inches in diameter.
21 feet. Impregnated grits, to porphyry. Strike N. 45° W. Vertical.
39 feet. Porphyry.
60 feet. Sandstones and shales, to fissure. Strike N. 65° W. Quartz.
81 feet. Massive green sandstones, to fissure. Strike E.-W.
12 feet. Sandstones, to pyrite body over porphyry. Strike NE.
66 feet. Porphyry, to northwest fissure, in porphyry.
117 feet. Porphyry.
400 feet. Surface wash and débris to mouth of tunnel.

Sunflower mine.—This is also on the south side of Allyn Gulch, at an elevation of about 10,300 feet. The workings, consisting of a shaft and tunnel, are abandoned as inaccessible. Considerable work is reported to have been expended on a "contact" lying above those described in the Forest-Payroll mine.

Laxey mine.—This mine lies on the northern spur of Dolores Mountain, at an elevation of about 9,500 feet. It was idle in 1900 and was not visited. It has never been productive.

Pro Patria (*Scoutt's*) *tunnel.*—This tunnel enters the northwestern slope of Newman Hill at an elevation of about 9,450 feet. Its course is S. 31° E., and in the summer of 1900 it had reached a length of about 2,000 feet. It is an extensive prospecting venture, being designed to cut the northern extension of the lodes worked in the Enterprise ground and to explore the blanket or blankets in connection with them. The tunnel penetrates Lower Hermosa sediments and intrusive sheets and dikes of porphyry. The shales and sandstones have a general southerly dip. At the face massive beds of sandstone were found dipping to the southwest at an angle of 21°.

Several veins have been cut having general northeasterly or northwesterly courses. But at the level of the tunnel these are small, and carry little save quartz and worthless pyrite.

South Park mine.—The adit of this mine is a tunnel run into the northwest base of Newman Hill from the bed of Silver Creek. As the workings were abandoned in 1900, and the water dammed back in the tunnel, the mine was not entered. For a distance of about 500 feet, in monzonite-porphyry, the tunnel follows a fissure striking a little south of east, which Cross and Spencer have designated the South Park fault. Apparently, no ore was found in connection with this fault fissure. About 350 feet south of it, however, a nearly parallel vein is said to have made a small body of good ore at its intersection with a bed of dark shale about 7 feet in thickness. The ore is reported to have been about 12 feet wide. The vein itself also carried ore for a distance of about 20 feet above and below the shale horizon. The strike of the beds, which are low in the Lower Hermosa formation, is about N. 30° W., and the dip is southwesterly at about 25°.

The occurrence of this blanket ore in the South Park mine is of interest, since it is found below the large intrusive sheet of porphyry that sweeps around the base of Newman Hill just east of Rico, and forms the country rock of the Skeptical shaft. The other ore-bearing horizons, however, such as the Enterprise, Union-Carbonate, Forest-Payroll, and New Year blankets are all above this sheet.

Hibernia tunnel.—This also enters Newman Hill from Silver Creek, about 600 feet west of the South Park. For about 350 feet the tunnel runs S. 12° E. It then turns and holds a somewhat crooked course to the east. Like the South Park, the tunnel enters in monzonite-porphyry and continues in this rock until a point is reached about 420 feet east of the turn, where the base of the sheet is passed through. At this place the porphyry sheet shows a westerly dip of about 15°. It is underlain by thin-bedded shales, sandstones, and limestones belonging to the lowest portion of the Lower Hermosa. A seam of gouge between the porphyry and the underlying sediments indicates some movement along this plane. About 110 feet farther east a fault, with a general north-and-south course, crosses the drift and brings porphyry on the east against Hermosa sediments on the west. This porphyry is apparently the same sheet just described, which is here faulted down on the east. Toward the breast of the tunnel the general southwesterly dip again carries the base of the porphyry up, and at the breast a bed of black shale about 1 foot thick underlies the porphyry, and is itself underlain by a bed of dark limestone, of which only the upper foot of thickness is exposed. The shale dips 12°, a little west of south. A little seam of fluorite occurs between the shale and the limestone.

The Hibernia was originally run to intersect the northerly continuations of the Enterprise veins. If its initial course had been maintained, however, it is doubtful whether it would ever have emerged from the massive sheet of porphyry. But by turning eastward it was enabled to come out beneath the porphyry, which here appears to dip a little west of south. Whether the bed of shale beneath the porphyry will be found ore bearing is unknown. The position of this shale between massive limestone and thick overlying porphyry is certainly favorable to its being locally brecciated and filled or replaced by ore in the neighborhood of vertical fissures. Assays of the almost undisturbed shale in the breast are said to yield $6 in gold per ton.

Numerous small veinlets are cut in the easterly crosscut of the Hibernia tunnel. They are of no importance and generally have a northwesterly course.

Onamo tunnel.—This is a crosscut, 1,400 feet in length, which enters the northwest slope of Newman Hill about 700 feet east of the Skeptical shaft at an altitude of about 9,350 feet. Its course is about

S. 23° E. It belongs to the Enterprise Company and was planned to connect with workings from the Laura shaft, but was never completed.

Isabella shaft and Wakeman tunnel.—The shaft was sunk east of the Enterprise adit at an elevation of 9,650 feet. It is reported that at a depth of 80 feet the Enterprise blanket was encountered, dipping southwest at an angle of 30°. The shaft was then abandoned, and an attempt was made to reach this blanket by a tunnel driven into the hill about 250 feet above the Group tunnel. This tunnel, however, has revealed the blanket dipping easterly, there being apparently a local syncline between the tunnel and the shaft. In an attempt to get around this depression without cutting through the shale roof of the blanket, and thereby letting in the surface waters, the tunnel has become exceedingly tortuous, and no connection has yet been made with the Isabella shaft. A little ore has been found in this portion of the blanket, but it is of too low grade to ship.

MINES OF HORSE CREEK.

PUZZLE MINE.

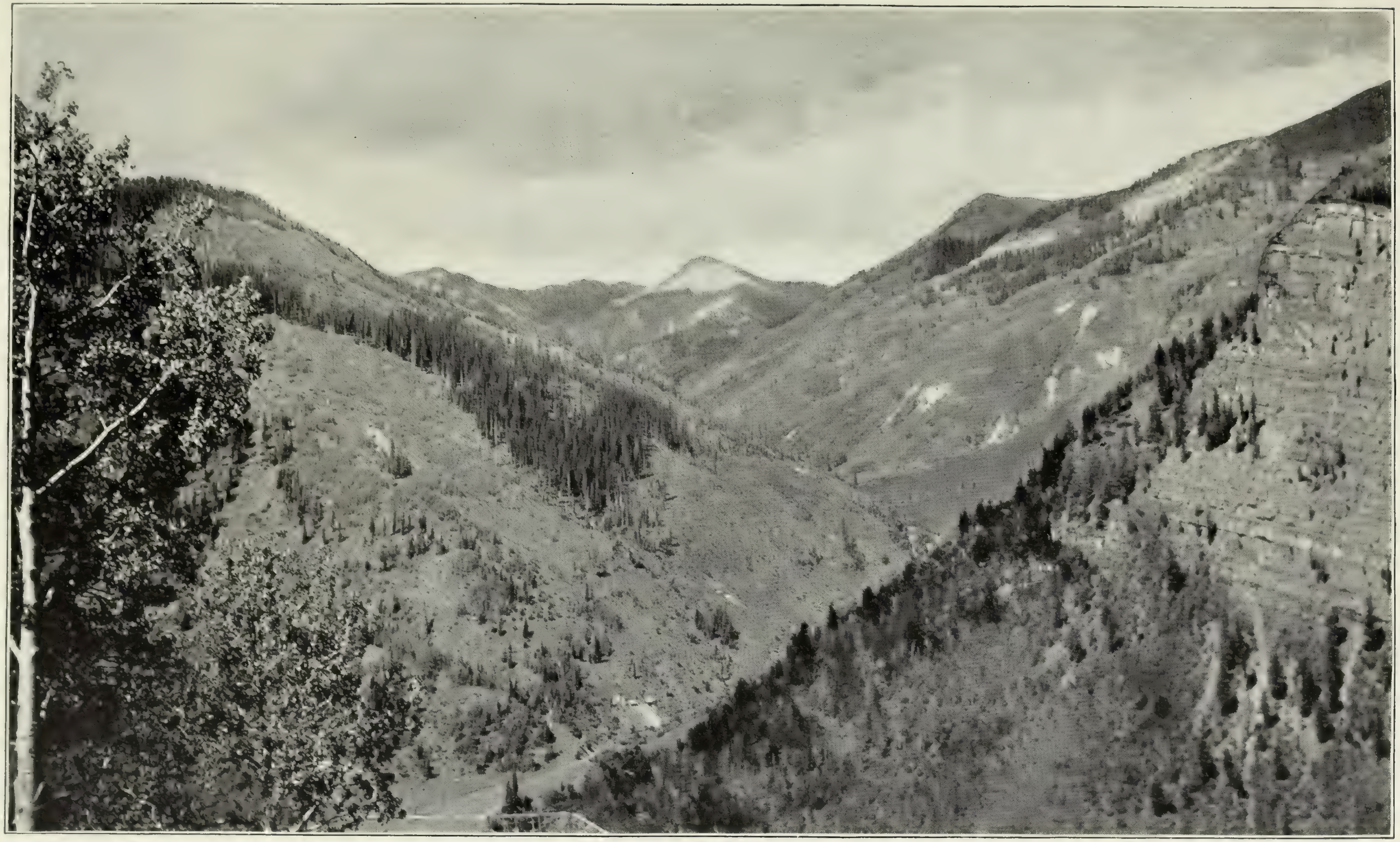
This appropriately named property occurs on the south side of Horse Creek, a little more than three-quarters of a mile from its mouth. As the geological map shows, it is in the lower part of the large landslide area forming the north slope of Darling Ridge.

The Puzzle mine was discovered about the year 1879 and during the first few years of operation produced nearly $300,000. The ore was a partly oxidized silver ore, frequently carrying from 600 to 1,800 ounces per ton and containing over 50 per cent of silica. None of this ore could be seen at the time of visit, but it was probably argentite, largely changed to native silver. C. W. Purington states in his unpublished notes that embolite, the chlor-bromide of silver, was also present. The ore was treated by barrel amalgamation in works situated about 1,000 feet south of the mouth of Horse Gulch. These have since been torn down.

After a few years the Puzzle ore body was worked out, and in 1900 the workings had long been abandoned and could not be entered. Many attempts have been made to find a continuation of the Puzzle ore body, but none of these have thus far been successful.

The country rock of the Puzzle (and Puzzle extension) consists of sandstones, shales, and limestones, belonging without much doubt to the medial division of the Hermosa. These are cut by one or more dikes of monzonite-porphyry.

These rocks, however, are not in place. They form a mass which has slipped for an unknown distance down the slope from the south, burying the former bed of Horse Creek and forcing the latter to swing



VIEW UP HORSE CREEK FROM C. H. C. HILL. CALICO PEAK IN THE DISTANCE.

On the right is a characteristic exposure of the Hermosa beds, on Sandstone Mountain

around the obstruction and cut a new bed to the north of the old one. This change in the course of the stream is indicated in the map (Pl. XLI).

A shaft 40 feet deep, sunk in the little swale which separates the Puzzle knoll from the main hill slope, passed through the landslide material and encountered buried stream gravels containing bits of wood. Gravels were seen in 1900 at the bottom of a winze sunk 20 feet below the Hess and Garren tunnel, about 100 feet from its mouth. They consist of well-rounded pebbles and bowlders of various rocks, of all sizes up to 10 inches in diameter. Mingled with these is much fine gravel and clay. This gravel rests upon a worn and irregular surface of black limestone, which in one place is cut by a dike of porphyry.

It is impossible to be certain whether the gravels just described are identical with those underlying the Puzzle ore and found in the bottom of the old shaft above referred to. It is highly probable that successive landslides took place, compelling the stream to change its course more than once. After such a slide the stream would be dammed, and would deposit silt and gravel above the obstruction. This deposit would in turn be buried by the mass of rock slipping or creeping down the slope from the direction of Darling Ridge.

The mode of occurrence of the Puzzle ore can at present be only imperfectly ascertained through conversation with those who formerly worked in the mine. It was an irregular replacement of the upper portion of a bed of dark fossiliferous limestone. On the north it was limited by the present stream bed, on the east by a fracture plane filled with gouge, and on the west was cut off by a mass of buried stream gravels. The ore-bearing limestone stratum is reported to have been greatly fractured and elevated toward the south by a succession of small step faults until finally cut off by a soft mass of crushed rock and gouge. It is not known what rock directly overlay the ore, although in some places broken rock and gouge is reported. Below the foot-wall limestone are the stream gravels of the old bed of Horse Creek.

The Hess and Garren tunnel, starting from the bed of Horse Creek, in the Puzzle Extension claim, just west of the Puzzle workings, runs in a direction S. 10° E. for about 325 feet. The rocks encountered are sandstones, shales, and limestones, all greatly disturbed. Bedding faults and cross fractures filled with soft clay gouge are numerous, and in many places the beds are reduced to a chaotic mass of fragments mingled with clay. At one point, perhaps 200 feet from the mouth, gravels were noted mixed with clay and angular rock débris. At the breast is a massive bed of black limestone overlain by shales and sandstones, all dipping north at 15°. Above the limestone is a prominent bedding fault filled with crushed shale and gouge. Other similar but smaller fault fissures occur in the overlying shales and sandstones. There can be no doubt that the entire tunnel is in landslide material, derived mainly from the Middle Hermosa.

A shaft sunk some years ago by J. O. Campbell on the Puzzle Extension ground encountered, at a depth of 60 feet, a bed of light ashy material about 12 feet thick. This layer consists partly of a pale sky-blue vitreous mineral, which was determined by Mr. C. W. Purington, through blowpipe tests, to be allophane, a hydrous silicate of alumina. The origin and association of the mineral at this occurrence could not be ascertained. Specimens show the allophane mixed with earthy material, the structure of the whole suggesting an alteration product of some unknown brecciated material.

M. A. C. MINE.

This property, lying on the hill slope, about 200 feet above the Puzzle mine, embraces two tunnels, a vertical shaft and an inclined shaft formerly known as the Hoosier Girl. The tunnels are prospects, run to find the original ore body from which that of the Puzzle was derived. The lower tunnel, at an elevation of 9,600 feet, runs S. 2° W. and is about 400 feet in length. It is all in limestone, which is so shattered as to require timbering throughout. The limestone, belonging to the middle division of the Hermosa formation, is irregularly fractured into large blocks separated by seams of unctuous clay gouge. It is all landslide material and not in place. It has slipped for an unknown distance down the slope of the hill, and the beds themselves have slid over each other and have been at the same time irregularly broken.

The upper tunnel is 50 feet higher than the lower and is about 550 feet in length. For 175 feet it runs S. 4° E. in thick-bedded dark limestone with a general northerly dip of 15°. This limestone is shattered into great irregular blocks separated by gaping crevices or by fissures a foot or more in width filled with yellow clay. Although the fragments are often confusedly jumbled, yet the original bedding is not entirely obliterated.

The tunnel then turns eastward and penetrates highly disturbed sandstone, shale, and limestone, and a little intrusive porphyry for a distance of nearly 300 feet.

About 275 feet from its mouth the upper tunnel connects with an incline leading to a vertical shaft. These workings show fine-grained sandstones and shales above the limestone in the tunnel. A little ore, chiefly copper carbonates in a calcite gangue, occurs, mixed with clay and breccia between the limestone and overlying sandstone. It varies from a few inches to a foot in thickness, but is of small lateral extent, being cut off by slip planes.

Both tunnels cut several shattered quartz veins, apparently of no value. One in the upper tunnel is 5 or 6 feet wide. No rock was seen in either tunnel which could be looked upon as being in place.

The old Hoosier Girl inclined shaft lies about 100 yards southeast of the lower M. A. C. tunnel. It is on a large vein apparently striking N. 75° W., but poorly exposed. The dip is to the south for the first 20 feet at an angle of 22°, and then increasing to 50°. The vein consists of barren, coarsely crystalline radial quartz. The centers from which the quartz has crystallized are often rhombs of calcite showing curiously dull and pitted surfaces, as if they had been attacked by some solvent before the quartz was deposited.

MOHAWK MINE.

This is in Mohawk Gulch, on the north side of Horse Creek, at an elevation of about 9,750 feet. The vein, having a general northwest-southeast strike, was worked through a crosscut tunnel, now caved in. The dump shows monzonite-porphyry and shale, with some pyrite and sphalerite. Both walls of the vein are said to be porphyry, probably a dike. The material on the dump shows that the porphyry in the vicinity of the fissure has been altered to a skeleton of cryptocrystalline quartz containing fine particles of pyrite. The larger feldspar crystals of the monzonite-porphyry have been removed, giving the siliceous alteration product a spongy texture, which reproduces to a certain extent the original porphyritic structure of the rock.

About 20 tons of ore, containing 40 ounces of silver per ton, is said to have been obtained from the mine in 1886.

The geological map of Cross and Spencer (Pl. XLI) shows a fault passing through the Mohawk mine. It is not known what influence this dislocation has upon the vein.

GREAT WESTERN MINE.

This is a prospecting tunnel about 2,000 feet west of the Puzzle mine, and on the north side of Horse Creek. The tunnel has a northwest course and is over 400 feet in length, the face being inaccessible owing to caving. It penetrates shales, limestones, and sandstones, probably belonging to the middle division of the Hermosa formation, with an intercalated intrusive sheet of porphyry. The general dip of these rocks is to the north at about 15°, and they are apparently in place, although the tunnel for 125 feet from its mouth passes through surface wash and slide. About 250 feet from its mouth the tunnel exposes a blanket about 6 inches thick, lying between shaly limestone below and shaly sandstone above. This layer of brecciated material is apparently not of great extent, and practically dies out in a distance of 25 feet to the west of the tunnel, where the shaly sandstone rests upon the limestone with but slight evidence of disturbance.

A second and stratigraphically higher blanket appears in the roof of the tunnel, about 300 feet from the mouth, and dips down toward the breast. This is a soft, dark breccia consisting of crushed shale, sandstone, and limestone, lying between two beds of limestone. In places it is at least 6 feet in thickness and contains within it a sheet of porphyry 3 feet thick, which has been altered to a soft gray clay containing much fine pyrite.

LACKAWANNA AND OTHER MINES.

West of the Great Western tunnel and scattered along Horse Creek are several small mines which were formerly worked and from some of which a few tons of ore were taken prior to 1887. They include the Lackawanna, Puzzler, Flying Fish, Roderick Dhu, Christina, Belzora, San Juan, and Golden 1900 (formerly the Sunnyside). These are all abandoned and no longer accessible. Most of them are on veins striking about N. 55° W., the Belzora and Christina being supposed to be on the same fissure.

High up on the north side of Darling Ridge, at an elevation of 10,700 feet, is the Magnet mine, in which a little work has been done upon a body of magnetite. This magnetite occurs as a replacement of limestone belonging to the Middle Hermosa, and has an average thickness of about 5 feet. The beds in which it lies strike southeast and northwest and dip northeast at about 45°. But the entire deposit is within the large Horse Creek landslide area and is probably not in place. That the ore is limited and cut off by faults, is shown even by the present very superficial workings.

The limestone which forms the hanging wall is cherty, but that upon which the ore rests is a soft white granular limestone, penetrated irregularly by streaks of magnetite and malachite.

The ore, which in its upper part is slightly oxidized, contains a little chalcopyrite. The best contains about 65 per cent of iron, with half an ounce of silver and a tenth of an ounce of gold per ton. A little was being mined in 1900 and sold to the smelter in Durango for use as a flux. But as the smelter allowed only $4 or $5 a ton for the iron and the cost of transportation amounted to $4 per ton, the operation could scarcely be very profitable.

The Uncle Remus mine, situated at an elevation of 11,350 feet at the junction of Darling Ridge with Expectation Mountain, was formerly worked through a shaft and tunnel. It is on an irregular vein in monzonite-porphyry, from which a little gold ore containing tellurium has been extracted. Chemical tests by Dr. H. N. Stokes show that a little molybdenum occurs in the ore. The workings were caved and abandoned in 1900.

There are several prospects on the South Fork of Horse Creek, including the Hand-Out, upon some of which considerable work has been done; but they were all abandoned and inaccessible in 1900, and no information concerning them was obtainable.

On the West or Middle Fork considerable tunneling has been accomplished on the Palmetto group, but no ore has been produced. There are various other small prospects in the vicinity, one of which—the Marriage Stake—is on a nearly vertical fissure in porphyry, striking nearly east and west. The fissure contains no vein quartz, but the porphyry for a width of 5 or 6 feet is silicified and impregnated with pyrite in the manner described on the Mohawk prospect.

JOHNNY BULL MINE.

This mine, situated in the saddle between Calico Peak and Johnny Bull Mountain, was opened in 1879, and in the course of one or two years produced about $100,000. The ore then became exhausted, and the mine has been abandoned for many years. The ore is said to have occurred in a "chimney," roughly circular in plan, and 10 or 15 feet in diameter. It was mined through a vertical shaft 123 feet in depth. This shaft is now caved in, and only a crater-like pit on the surface marks the site of the former ore body. A tunnel 190 feet in length was run in from the west side of the ridge in 1882 to connect with the shaft. The connection was effected, but the ore gave out at this point.

The country rock of the Johnny Bull consists of fine-grained sandstones and shaly limestones belonging to the Dolores formation, cut by sheets and dikes of monzonite-porphyry. As seen in the crater-like depression above the old workings, the ore body was inclosed in a very fine-grained, nearly white sandstone, which is minutely impregnated with pyrite and traversed by small, irregular dikes of porphyry. Close to the ore this sandstone contains abundant pyrite, is traversed by irregular streaks which differ from the rest of the rock in containing numerous spots of kaolin, and is often strongly silicified. The gangue of the ore is composed of cryptocrystalline quartz, full of minute vugs, which has resulted from the complete silicification of the fine-grained sandstone. This silicification extends irregularly into the inclosing country rock, particularly along bedding planes.

Below the ore body a vein was encountered in the crosscut tunnel already mentioned. This vein strikes N. 25° W. and dips northeast, and as shown by the dislocation of beds of sandstone and a sheet of porphyry which it cuts, corresponds to a small normal fault. This fissure is less than a foot wide and contains crushed rock, gouge, and a little ore. The Johnny Bull ore body was apparently deposited from this fissure through silicification and replacement of certain beds favorable to such metasomatic action. The localization of the deposit as a "chimney" appears to have been due to the existence of one or more cross fractures.

The ore of the Johnny Bull consisted of enargite, pyrite, black oxide of copper, free gold, and probably other minerals. It was of high grade, both in gold and silver. Chemical tests made by Dr. H. N. Stokes showed that some of the ore contained tellurium and traces of bismuth.

GOLD ANCHOR MINE.

This is entered by a tunnel about 700 feet in length, which runs from Bull Basin in a direction N. 65° W., and passes under the Johnny Bull workings. The tunnel passes through conglomeratic white sandstone, fine-grained sandstones, and shaly limestones belonging to the Dolores formation.[1] These beds strike N. 15° E. and dip westerly at about 25°. They are cut by several dikes of porphyry, which in some cases contain phenocrysts of kaolinized feldspar up to 2 inches in length, and by one clastic dike 8 inches wide, filled with firmly consolidated fragments of sandstone and grit, with some quartz pebbles.

About 450 feet from its mouth the tunnel cuts the Anchor vein, striking north and south, and dipping east at about 70°. Where seen, this vein is chiefly a soft gouge, showing evident signs of recent movement. It shows a porphyry dike or sheet on the hanging wall. Some specimens of ore from this vein show metasomatic replacement of fine-grained light sandstone by pyrite and tetrahedrite. The process of ore deposition is closely similar to that in the Johnny Bull.

Nearly 600 feet from the mouth the tunnel intersects a fissure which is supposed to be the Johnny Bull vein. It strikes about N. 50° E. and dips southeast 50°. At the tunnel it is a mere seam of soft gouge, less than 5 inches wide, carrying a little pyrite and traversing fine-grained sandstone. This fissure was drifted on for about 60 feet to the northeast, where it opened into a small "chamber" or stock of pyrite about 10 feet in diameter. Some of this pyrite upon assay afforded over 90 ounces of gold, and it was stoped up for 45 feet. But as a whole the ore did not pay the cost of its extraction. A little tetrahedrite was associated with the pyrite. The ore body, like that of the Johnny Bull nearly directly above it, was formed by local replacement of fine-grained sandstone and shale adjacent to the fissure. It may well be doubted whether this fissure is the same as that of the Johnny Bull, as the two (as nearly as could be determined by the short exposures available) are divergent in dip and strike.

OTHER PROSPECTS IN BULL BASIN.

The Albion (formerly the Victoria) was formerly worked through two shallow shafts and produced a small quantity of pyrite and tetrahedrite ore from a small irregular fissure.

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[1] It is of interest to note that the red color so characteristic of the Dolores formation of the Juratrias on surface exposures disappears underground (at least in this region) and the beds become nearly white.

The Caledonia (formerly the Rico) is supposed to be on the same vein as the Albion. It was opened by a shaft and tunnel and is reported to have yielded a little "black copper" ore. The vein as seen in the shaft strikes N. 40° W. and dips northeast at 85°. It is composed of solid quartz up to 16 inches wide, carrying sphalerite and pyrite.

The Utah claim, on the north side of the lower part of the basin, is on a large vein of barren white quartz striking N. 55° W. and dipping 50° to the northeast. The country rock is pebbly sandstone of the Dolores formation. Considerable drifting has been done on this vein, which is sometimes over 3 feet wide. The quartz is fractured and crushed, and shows no mineralization beyond an occasional speck of pyrite.

MINES OF THE EASTERN SLOPE OF EXPECTATION MOUNTAIN.

N. A. COWDREY MINE.

This is situated on Sulphur Creek at an elevation of 8,850 feet. The workings consist of a tunnel something over 500 feet in length, running S. 60° W., and some stopes in a blanket. The tunnel follows an irregular bunchy lode, in massive fine-grained sandstone belonging to the Lower Hermosa, and dipping S. 30° W. at an angle of 20°. Low-grade ore, consisting of pyrite, galena, and sphalerite in a quartz gangue, occurs in the larger portions of the lode, which often splits into irregular and discontinuous stringers. The general dip of the lode appears to be southeasterly, at a high angle.

About 500 feet from the mouth the tunnel cuts a blanket, which is composed of a bed of black shale about 18 inches thick, resting on massive sandstone. Above the shale is about 3 inches of limestone, then 18 inches more shale, and then massive sandstone. Near the lode the lower shale is crushed and veined with quartz. The ore occurs near the bottom of the bed, resting on the sandstone. It consists chiefly of galena and sphalerite, and is of low grade. From 100 to 200 tons have been extracted, but the mine is now idle.

The main lode appears to pass upward through the blanket, although its identity is obscured within the mineralized shales.

TOMALE MINE.

The abandoned workings of this mine are also on Sulphur Creek, about 50 feet higher than the N. A. Cowdrey. The adit tunnel follows an ore-bearing stringer striking S. 55° W., and dipping northwest at an angle of about 75°. The stringer is usually about an inch wide and carries galena, sphalerite, chalcopyrite, and pyrite, with very little quartz. The country rock is fine-grained massive sandstone of the Lower Hermosa, which is traversed by several other stringers generally parallel to the one followed.

About 60 feet from the mouth of the tunnel the stringer is cut off by a fault which strikes N. 50° W. and dips 60° NE. This fissure carries white quartz and some pyrite, the whole being somewhat crushed. and accompanied by gouge.

A crosscut of 18 feet to the northwest along this fault shows that the country rock is traversed by many small veins, generally parallel to the one followed in the tunnel. Some of these carry ore. Others, like the fissure faulting them, contain only quartz and pyrite. At the end of the crosscut, a stringer about 3 inches wide, of solid galena, sphalerite, and chalcopyrite, was encountered in the southwest side of the crosscut, cut off sharply toward the northeast by the fault. This stringer was then drifted on as the main vein, but it is by no means certain that it is the same as the ore originally followed northeast of the fault. This lead was drifted on for 150 feet, but it maintained its character as a small, tight-branching stringer, and the prospect was finally abandoned.

ARGONAUT MINE.

This mine is also on Sulphur Creek and is entered through two tunnels a few yards upstream from the Tomale adit. These tunnels are separated by a vertical distance of about 50 feet, both entering in the same sheet of porphyry. In the lower level a crosscut of 125 feet gives access to the lode, which strikes N. 40° E. and dips northwest at an angle of 60°. About 150 feet of drifting on the vein was accessible on this level at the time of visit. The lode varies in width up to a maximum of 1 foot. It frequently splits up into a stringer lead which is too lean to work. The ore consists of galena, sphalerite, chalcopyrite, and pyrite, in a gangue of unusually spongy quartz, full of minute vugs. There is usually a gouge on both foot and hanging walls.

The vein has been stoped through to the upper tunnel, which enters in porphyry, but finally cuts through the upper surface of the sheet into overlying shales and fine-grained massive sandstones and limestone belonging to the Lower Hermosa. These beds dip S. 15° E., at an angle of 40°. The unusual steepness of this dip is probably due to local irregularity consequent upon the intrusion of the porphyry.

The lode in this level preserves the general character already noted. The ore, however, is sometimes nearly free from quartz, and the existence of sheeting and minor veining of the country rock alongside the main fissure is better shown.

It is reported that the ore did not extend up into the shale which immediately overlies the sheet of porphyry. At the time of visit the top of the old stopes was not accessible, but G. W. Tower records in his notes that the overlying shales are brecciated and the limestone silicified, but that no ore was deposited.

No work has been done on this property for years.

BANCROFT MINE.

This lies about 1,500 feet north of the Argonaut, and, like most of the properties in the vicinity, is at present little more than an abandoned prospect. It was proposed in 1900, however, to reopen it for zinc ore. It has been opened by a tunnel and shaft. The tunnel follows a vein striking N. 50° E. and dipping northwest at 75°. The country rock is Lower Hermosa sandstone, dipping south at an angle of 15°. A second parallel vein lies about 12 feet to the northwest. Resting directly upon the sandstone is a layer of soft shale breccia and yellow clay from 2 to 3 feet thick, overlain by shale. The northwest vein is apparently cut off sharply at the base of this breccia. The other vein, the one followed by the main tunnel, loses its vein character upon reaching the breccia, and the latter shows a little ore, while the underlying sandstone is also slightly mineralized. It is reported that some ore was stoped from this blanket, extending to a distance of 30 feet from the fissure.

Most of the old workings are no longer accessible, and although some highly sphaleritic ore was seen on the dump, it was not seen in place except in small amounts in the northwest vein. The same sheet of porphyry cut in the Argonaut workings was apparently encountered in the Bancroft shaft and in the abandoned St. Louis shaft, a little higher up the hill.

SILVER SWAN MINE.

The adit of this mine is a tunnel some 900 feet in length, entering the mountain about 500 feet south of Sulphur Creek, and near the level of the Dolores River. This tunnel runs S. 80° E. in Lower Hermosa sandstones, shales, and limestones. It cuts several small veins of no economic importance as far as known. Near the breast of the tunnel a raise of 60 feet connects with a short upper level. Here a small and irregular vein followed in the lower level becomes much larger, striking N. 80° E. and dipping north at 70°. At the west breast of this upper drift the vein shows a foot of ore next the hanging wall, consisting of galena, sphalerite, chalcopyrite, and pyrite, with about 3 feet of sheeted sandstone and ore-bearing stringers on the foot wall.

Another rise of 12 feet gives access to a higher level, which at its western end cuts a well-marked blanket. This consists in its lower part of about 6 inches of soft gray clay or gouge, above which is an unknown thickness of black shale which has been shattered and crushed to a tough clayey mass. The whole "contact," which undoubtedly represents a pronounced bedding fault, rests upon sandstone dipping 10° or 12° to the southwest.

The main lode is said to spread out to a width of 20 feet and to carry galena ore immediately below the gray gouge. The veins are certainly cut off squarely at this horizon, but the development is not yet sufficient to determine the precise mode of occurrence and extent of the ore bodies.

The ore so far found is of low grade, with its value chiefly in silver. It has not yet been produced on a commercial scale.

LITTLE MAGGIE GROUP.

This is a group of prospects on the west bank of the Dolores River, about 800 feet north of Sulphur Creek, and includes the Little Maggie. Birchard, and Hardscrabble claims. The several tunnels and drifts in Lower Hermosa beds expose a blanket closely resembling that of Newman Hill. It rests upon a bed of limestone and is overlain by dark shale. It consists chiefly of a shale breccia and contains a few small bunches of ore. The limestone and shales beneath this blanket are traversed by numerous small stringers of white quartz, but no work has been done to determine whether these indicate the presence of a vein or veins beneath. Various incipient or local blanket breccias were noted in the dark shales at different stratigraphic horizons.

IRONCLAD MINE.

This lies about 500 feet north of the Little Maggie group, in Lower Hermosa beds, striking northwest and dipping southeast at 15°. The tunnels of this mine were caved in at the time of visit. The main vein is reported by G. W. Tower to have a course of N. 55° E. This vein is said to have yielded about 300 tons of ore, containing 30 ounces of silver per ton and 6 per cent of copper, from a pocket encountered at its intersection with a fissure running N. 30° W.

WHIM MINE.

This property, no longer accessible, was opened by four tunnels about 200 feet north of the Ironclad. Tower states that a vein striking N. 50° W. is slightly faulted by a vein trending N. 20° E., and that both carry galena in a gangue of quartz and calcite.

LITTLE LEONARD MINE.

This prospect is situated between Iron Draw and Sulphur Creek, at an altitude of about 9,800 feet. There are several tunnels, of which the lowest only was accessible at the time of visit. This is about 300 feet in length and cuts a number of northwest-southeast fissures in monzonite. These are unusually numerous and have rather flat southwesterly dips ranging from 10° to 40°. They frequently contain nothing but gouge, although there is sometimes a little crushed quartz present. No ore was seen.

MONTEZUMA MINE.

This is opened by two tunnels about 150 feet above the settlement known as Piedmont, which lies north of and just across the river from Rico.

The lower tunnel is about 300 feet in length and has a course of N. 55° W. for about half the distance and then turns N. 70° W. It follows a tight and irregular vein which dips southwest about 70°. For a distance of nearly 250 feet from the mouth of the tunnel the country rock is quartzite, referred doubtfully to the Devonian. Beyond this appear limestone, sandstone, and shales, belonging to the Lower Hermosa, and dipping S. 10° W. at an angle of 15°. Associated with these beds is some intrusive porphyry, apparently a sheet connected with the large eruptive mass which extends up the spur between Aztec Gulch and Iron Draw.

At the point where the tunnel emerges from the Devonian quartzite it cuts a very irregular blanket, consisting of crushed and pulverized rock, gouge, and ore. This material rests partly on the quartzite and partly upon monzonite-porphyry. It is overlain by shales and sandstone. It is apparently a bedding fault along a bed of limestone, which has been broken up and partly replaced by ore. The latter consists chiefly of pyrite and chalcopyrite in a gangue of quartz and chlorite. A little galena has also been found.

This blanket ore is directly connected with the main vein, which continues up through the overlying sediments, and which, as far as could be determined, is not a plane of perceptible faulting. The porphyry and quartzite that underlie the breccia are impregnated with pyrite. Part of the quartzite shows in addition intense metamorphism of a kind not usually associated with ordinary ore deposition. In its initial stages this alteration consists of the development of green hornblende in the interstices of the quartzite. But where the process has been complete the quartzite is replaced by a coarsely crystalline aggregate of pale-green hornblende, pyroxene, and epidote. In other places the metamorphosed rock consists of coarsely crystalline pyrite, chlorite, quartz, and dolomite. This metamorphism is evidently of the same origin as that so noticeable in the Atlantic Cable, Shamrock, and Smuggler claims, and generally prevalent in the Devonian rocks just north of Rico.

The upper tunnel follows a small vein lying a little north of and generally parallel to that followed in the lower tunnel about 25 feet below. On the north side of this tunnel a flat deposit of iron pyrite, in a matrix consisting chiefly of chlorite and ranging in thickness from 1 to 2 feet, extends to an unknown distance from the vein. It dips southward at a small angle. It is a replacement along a bedding plane in the quartzite, which shows a somewhat similar alteration to that already described.

The Smelter fault, as described by Cross and Spencer, must pass through or very near the upper tunnel of the Montezuma, but the workings themselves fail to reveal its presence.

CALUMET MINE.

This prospect is of interest through being on a vertical fissure, which is probably a branch of the Last Chance fault.[1] It is opened by a tunnel 500 feet in length, which enters about 1,000 feet south of Aztec Gulch and about 100 feet above the Dolores River. The vein is 4 or 5 feet in width, but without regular walls. It is filled with quartz, usually much crushed, containing bunches of pyrite.

The country rock near the mouth of the tunnel is fine-grained sandstone, changing near the breast to shale and intrusive porphyry. It is all more or less impregnated with pyrite and chalcopyrite, and the porphyry in particular is traversed by numerous minute stringers of quartz and pyrite and decomposed to a soft gray mass. Stringers containing quartz and pyrite and striking northwest and southeast are very numerous.

AZTEC MINE.

This mine, one of the first to be opened in the district, is situated in Aztec Gulch at an elevation of about 9,600 feet. It has been worked very irregularly for various short periods since 1879 and has made some small shipments of ore. About 24 tons were produced in 1895, which carried from $2 to $3 in gold and 17 ounces of silver per ton and 11 per cent of lead.

The developments are confined to some tunnels and small stopes on the Aztec lode. This strikes about N. 70° W. and dips north at from 80° to 85°. The country rock consists of shales, sandstones, and shaly limestones of the Lower Hermosa formation.

As exposed in the upper tunnel, the vein consists of white banded quartz, 3 feet in width, the banding being due to thin films of partly silicified gouge or shale inclosed in the quartz. This quartz is practically barren, containing only a little pyrite. On the footwall is a breccia of shale and shaly limestone about 2 feet wide, which passes without definite wall or gouge into the undisturbed shales and limestones forming the country rock (fig. 62). Both breccia and country rock are mineralized, chiefly with pyrite, to a distance of at least 5 feet from the vein. Much of this mineralization is a metasomatic replacement of calcareous shale bands similar to that described (fig. 60, p. 345) in the Union-Carbonate mine.

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[1] Cross and Spencer, loc. cit., p. 120.

On the hanging wall of the vein is a somewhat similar breccia, the width of which is not certainly known; but it is at least 5 feet. This breccia consists chiefly of shale fragments, often cemented by white quartz, and sometimes by ore.

The geological work of Cross and Spencer has shown that the Nellie Bly fault, which passes over the point of Nigger Baby Hill, probably extends through Aztec Gulch. The character of the Aztec vein certainly indicates that considerable differential movement has taken place along this fissure. The development of the mine, however, is not sufficiently extensive to determine the throw of the fault at this point.

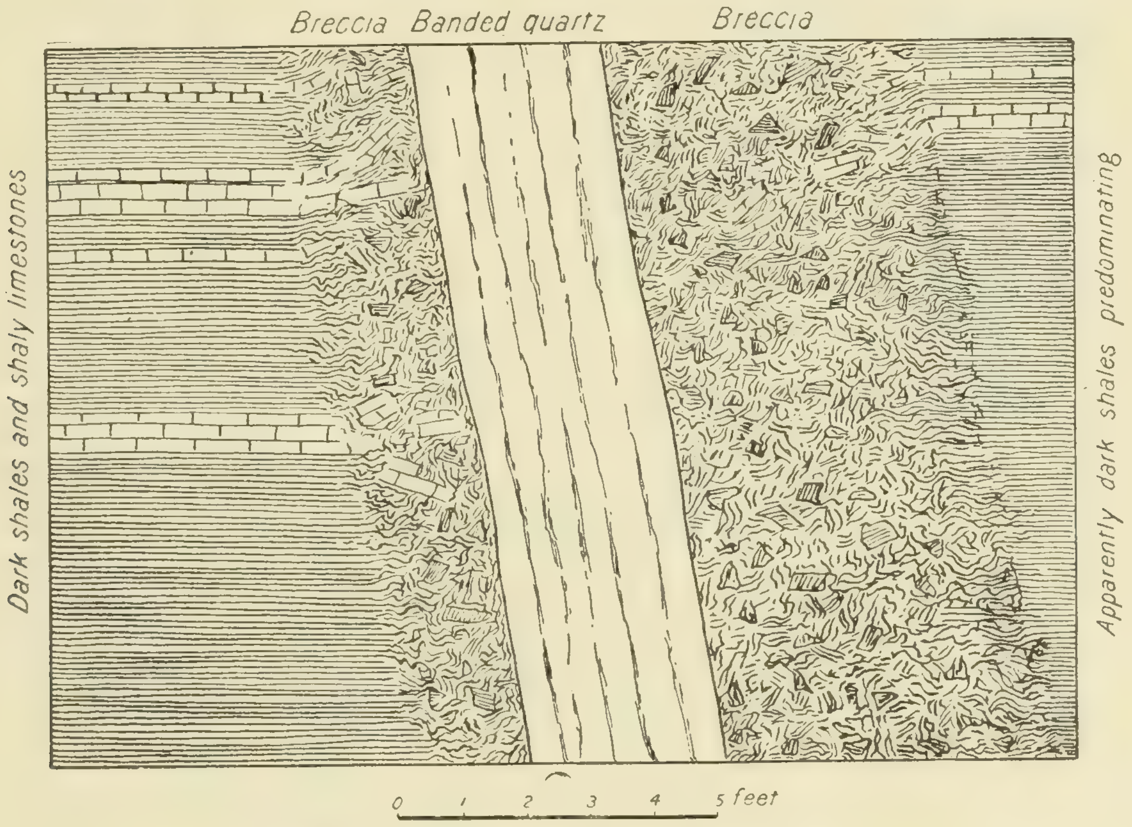
Breccia
Banded quartz
Breccia
Dark shales and shaly limestones
Apparently dark shales predominating
0
1
2
3
4
5 feet

FIG. 62.—Cross section of the Aztec lode.

The Columbia claim, also an early location, is on the same vein as the Aztec, and is situated a few hundred feet lower down the gulch. It has not been worked for years.

SAMBO MINE.

This mine lies on the northeast slope of Expectation Mountain, between Horse Creek and Aztec Gulch. The principal adit is a tunnel entering the hill at an altitude of about 9,250 feet. The main workings are shown in the sketch plan of fig. 63. They are in shales and sandstones belonging to the Lower Hermosa.

Several veins are cut by the tunnel, as shown in fig. 63, but they have not proved of any importance. The main Sambo vein is usually from 3 to 4 feet wide, composed of solid mottled quartz carrying a little pyrite. The mottling is due to numerous silicified fragments of shale included in the vein. The vein strikes N. 75° W. and dips northward at about 65°. It occupies a fault of at least 4 or 5 feet throw. But whether normal or not, could not be determined. This vein is itself of no value, but immediately above the top of the drift it is connected with a blanket of quartz and ore inclosed in shales, while a smaller portion of the vein continues upward across the beds (fig. 64).

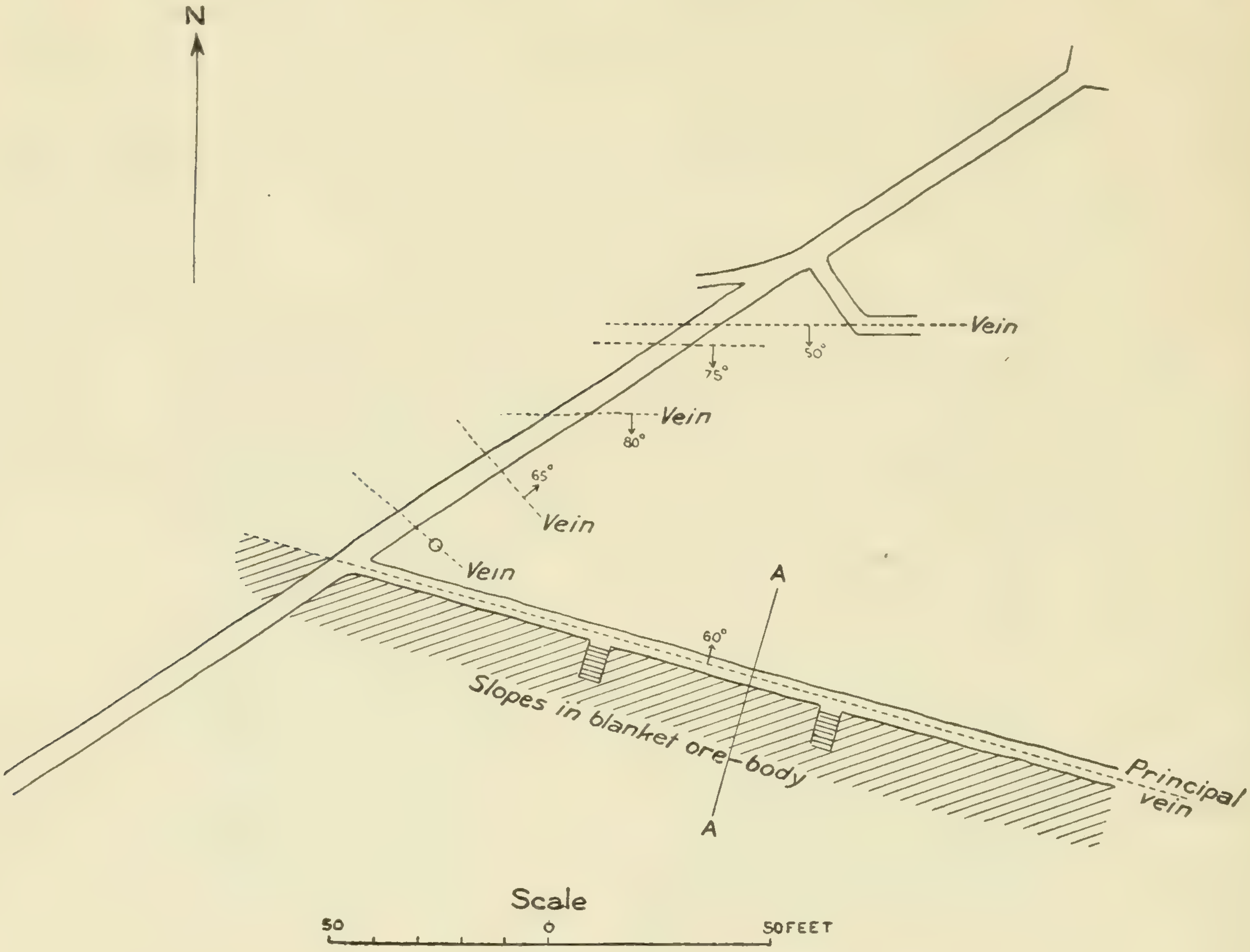

FIG. 63.—Sketch plan of the Sambo mine.

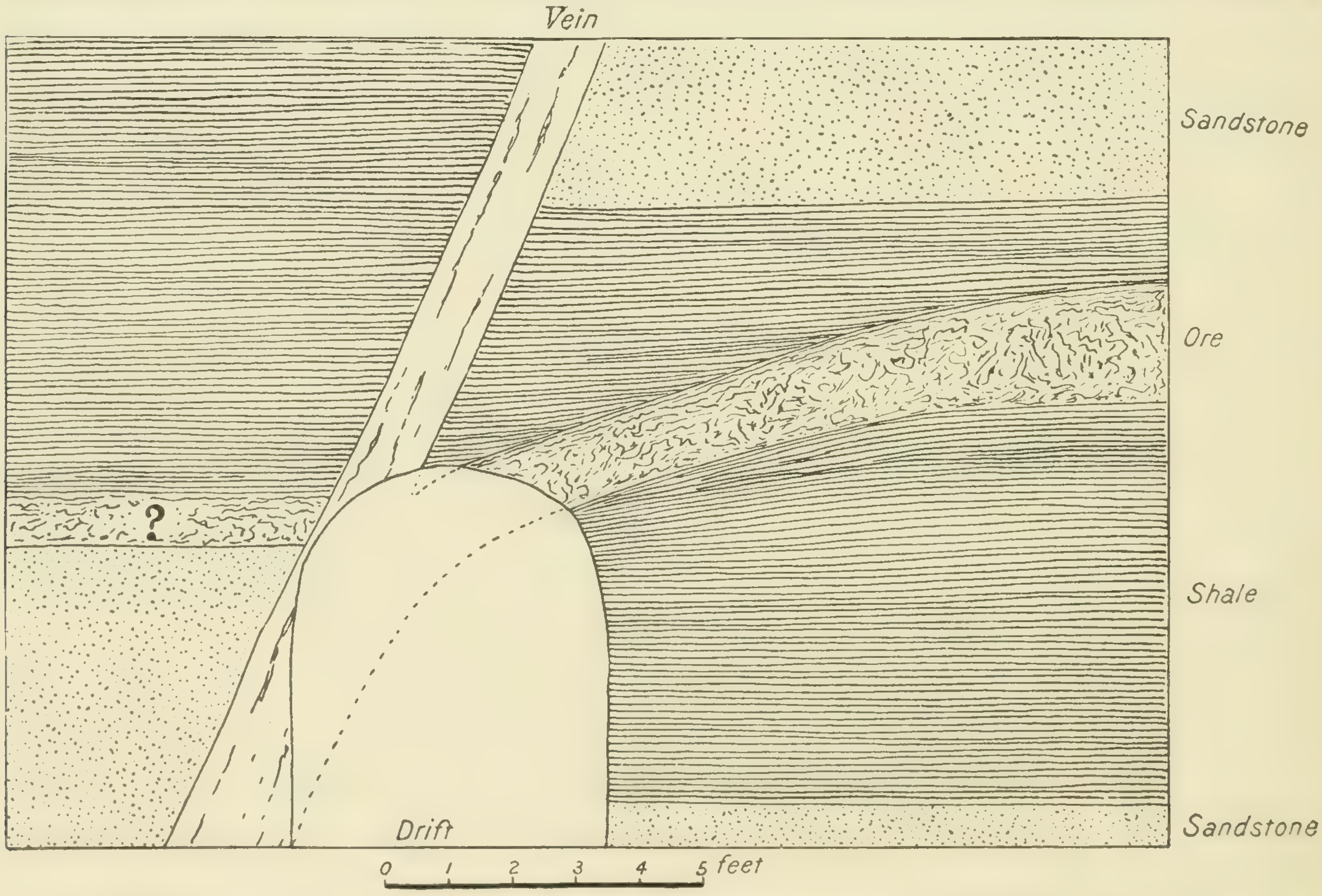

FIG. 64.—Cross section of the Sambo vein and blanket ore body, on the line A–A of fig. 63.

The blanket deposit occupies a bedding fault between black shales below and gray calcareous shales above. The resulting shale breccia is in places completely replaced by a mass of quartz and ore, which extends to a distance of about 30 feet to the south of the drift. Beyond this the silicification dies out and the bedding fault is not mineralized. Owing to the inclusion of numerous shadowy fragments of silicified shale, the quartz has a decided mottled appearance.

The best ore consists of galena and tetrahedrite, but sphalerite is very abundant in some portions, together with pyrite and chalcopyrite. The stopes in the blanket indicate that considerable ore has been extracted, but the mine was idle at the time of visit.

The ore-bearing bedding fault has not been found on the north side of the vein, nor, apparently, has any search been made for it. The bedding fault is probably older than the vein, and was itself dislocated by the latter. It is very probable that the bodies of ore will some time be found on the north side of the fissure vein at a different level from those already extracted.

ZULU CHIEF MINE.

This is an abandoned prospect, situated near the head of Iron Draw, at an altitude of about 10,700 feet. It was opened through two tunnels, of which the lower is shown in plan in fig. 65. The workings are in shales, sandstones, and limestones of the Lower Hermosa formation, cut by at least one large dike of porphyry.

No ore was seen, and the chief interest in the mine is the occurrence of two strong fissures, cut by the tunnel, one of which probably corresponds to the Aztec lode fissure and the Nellie Bly fault. The first of these fractures is encountered about 200 feet from the mouth of the tunnel. It is a strong breccia zone about 10 feet wide, filled with fragments of shale and wet clay, with some quartz near the hanging wall. The dip of the fissure is southerly and its strike apparently nearly east and west, but neither could be accurately measured. The hanging wall shows shales and sandstones, while the very irregular footwall is limestone, which is shattered and irregularly veined with quartz for a distance of 50 feet from the fissure.

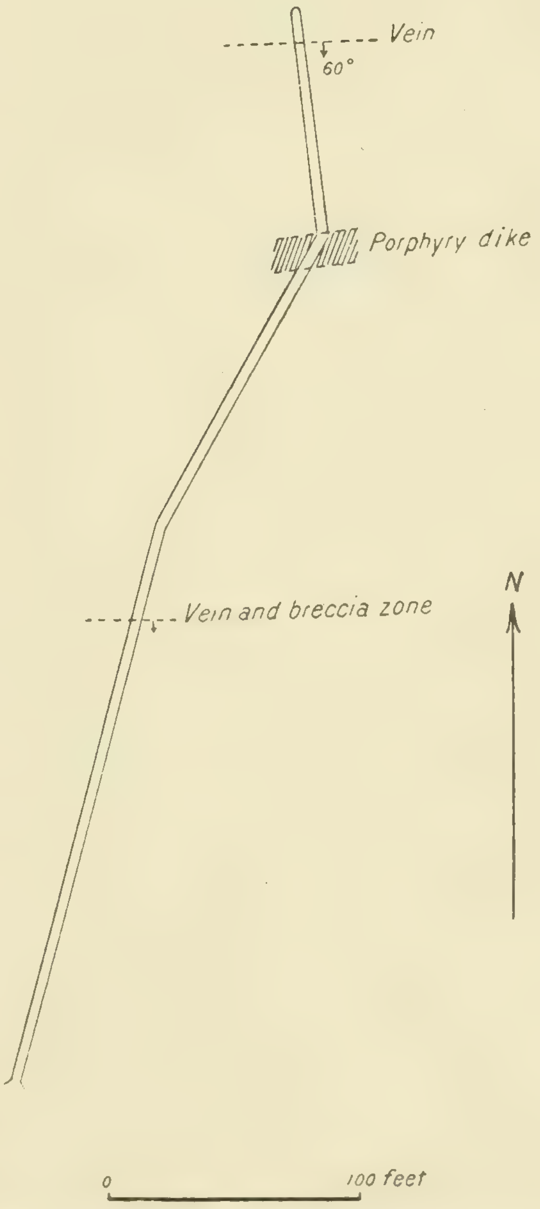

FIG. 65.—Sketch plan of lower tunnel of the Zulu Chief mine.

A second fissure, about 4 feet wide, was cut near the breast of the tunnel. The middle of the fissure is occupied by a vein of barren, banded quartz, 2 feet wide. This is separated from the hanging wall by 6 inches of gouge and broken shale, and from the foot wall by 18 inches of similar material with some soft oxide of manganese. This lode thus resembles, in general character, the Aztec. It strikes east and west and dips 60° to the south. The country rock near the breast of the tunnel consists of calcareous shales dipping N. 15° E. at 30°.

Besides the fissures described, several smaller ones, with general east and west trend, are intersected by the tunnel.

CALIFORNIA MINE.

This prospect lies near the head of Iron Draw, at an elevation of about 10,300 feet. There are two tunnels in limestones, sandstones, and calcareous shales, belonging probably to the middle division of the Hermosa formation. These are cut by dikes of monzonite-porphyry. The tunnels intersect several strong fissures, striking from N. 70° W. to S. 85° W. Most of these fissures contain gouge, with some quartz, and occasional bunches of galena ore, none of which have been rich enough to ship. In the upper tunnel are some blankets of pyrite, 6 to 8 inches thick, connected with one of the veins and replacing some disturbed beds of calcareous shale. A little native copper was noted in cracks in the sandstone in the lower tunnel. One or more of the fissures found in this prospect probably correspond to the Aztec lode.

MINES CONNECTED WITH THE BLACKHAWK FAULT.

BLACKHAWK MINE.

Situation.—The Blackhawk and Maggie mines, which have been worked in conjunction, lie on the northern side of the steep spur which separates Allyn Gulch from Silver Creek, in a shallow ravine marking the line of the great Blackhawk fault. This fault, as outlined by Cross and Spencer, can be traced from the saddle of Telescope Mountain, in which are the Uncle Ned and World's Fair mines, down to the Argentine shaft in Silver Creek, and thence up the Blackhawk ravine. Near the lowest level of the Blackhawk, at an elevation of about 9,800 feet, the fault fissure appears to split into two or more branches, and from here on, until it passes over the western shoulder of Blackhawk Peak, it is a zone of faulting rather than a single fracture. The Blackhawk mine lies on the northeastern edge of this fault zone.

History and development.—The mine has been worked through a series of tunnels ranging in altitude from 9,750 feet to about 10,600 feet. The highest opening is the Little Maggie shaft, an incline on the vein at 10,700 feet. As shown by the section (fig. 66), the vertical distances between these levels are not uniform.

The mine was first worked in 1879, and during the following years much high-grade oxidized silver ore was extracted from the Little Maggie vein, above the M level. From a varying distance above this level, up to the surface, the vein has been stoped out.

Below the M level the Little Maggie fissure, if it has been found, contains no workable ore. Large bodies of sulphide ore were discovered, however, on the northeast side of the vein. These are replacements in beds of limestone dipping away from the vein to the northeast, and were worked until about 1899, when the mine, for the time being, was abandoned.

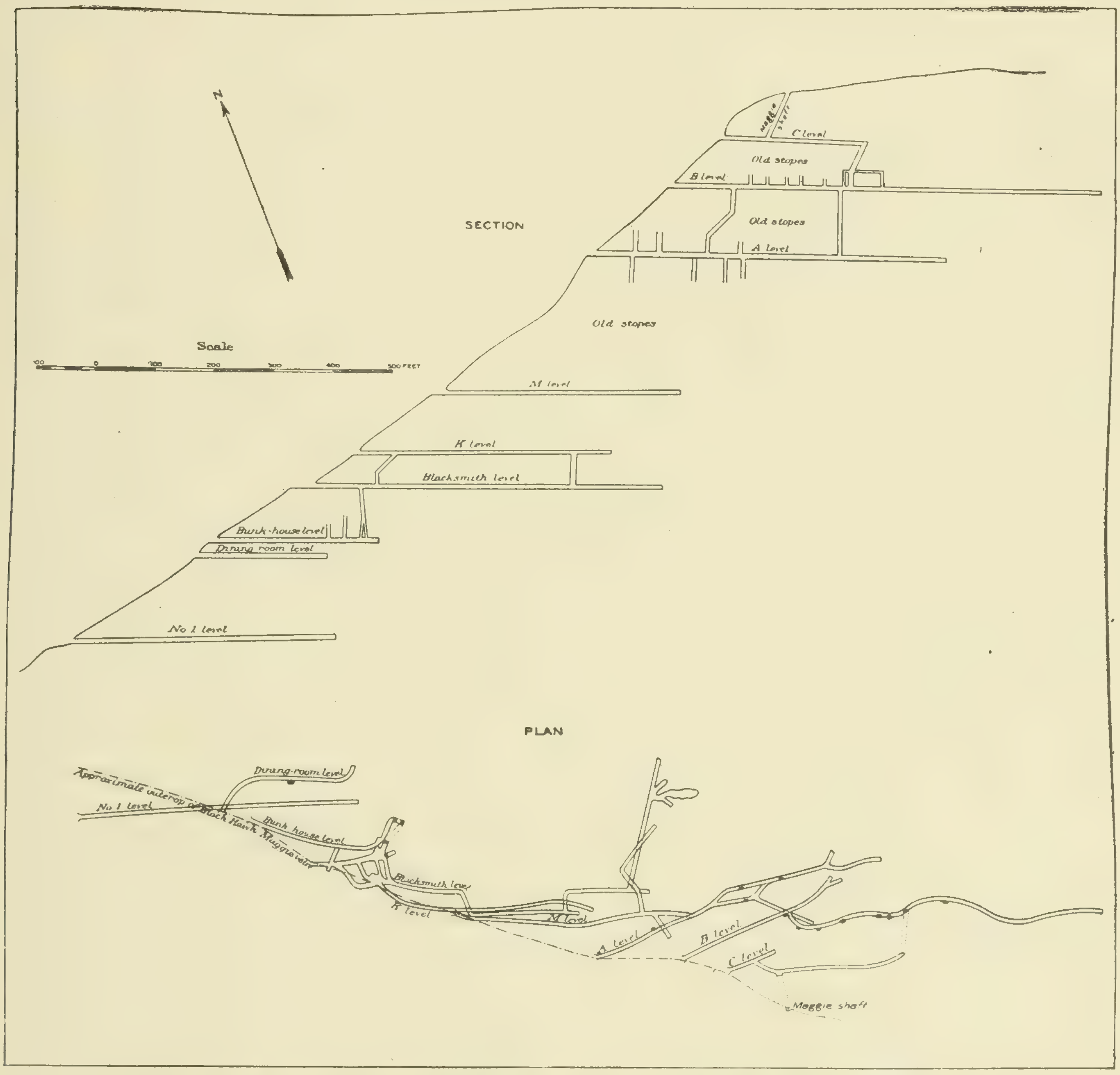

FIG. 66.—Plan and longitudinal section of the Blackhawk mine.

Although most of the workings were accessible in 1900, yet the lack of clean exposures, and of some one at hand familiar with the mine, rendered the study of the ore bodies difficult and unsatisfactory.

Occurrence of the ore.—From the surface nearly down to the M level, a vertical distance of about 500 feet, the ore occurred in a simple fissure vein, striking about N. 70° W. and dipping northward at about 60°. This ore, which has all been stoped out, was a soft, black, earthy material, containing much oxide of manganese, largely derived from rhodochrosite. Toward the southeast, the ore body was limited by the contraction of the fissure to a small gouge seam. Toward the northwest the identity of the Little Maggie vein is lost at its junction with the Blackhawk fissure zone. The country rock consists of sandstones, shales, and thin limestones belonging to the upper division of the Hermosa, and dipping northeastward at about 30°. These beds are not perceptibly faulted by the Little Maggie fissure.

The relation of the Little Maggie vein to the Blackhawk fault is not perfectly clear. The general course of the latter is about N. 40° W., while the average course of the Little Maggie is N. 70° W. The Blackhawk fault is nearly vertical,[1] while the Little Maggie vein has a northeasterly dip of about 60°. As a consequence of these conditions and of relations of the fissures to the topography, the outcrop of the Little Maggie vein is practically parallel with the outcrop of the fault. About 150 feet southwest of the Little Maggie vein on the surface is a large solid vein of barren white quartz, in places fully 15 feet wide. The apparent strike of this vein is N. 40° W., corresponding to that of the Blackhawk fault, and it dips northeastward, seemingly at an angle of about 65°. Between this vein and the croppings of the Little Maggie is a much-disturbed and fissured strip of country rock traversed by many veins. This strip occupies the bottom of the little ravine which has been partly filled up by the dumps of the Blackhawk mine. The large southwestern vein has been only very superficially prospected, although it has apparently been cut in the Blacksmith level. It could not be determined whether it represents the main fissure of the Blackhawk fault, which is stated bv Cross and Spencer to have a throw of from 600 to 800 feet in this vicinity, or whether this great dislocation has taken place along some fissure lying just southwest of the vein, and not prominently shown on the surface. The workings of the Blackhawk mine throw very little light upon the fault, inasmuch as they appear to lie entirely on its northeast side. Some years ago a tunnel 400 or 500 feet in length, known as the Wildcat, was run through Lower Hermosa beds in a direction N. 70° E., from the northeast side of Allyn Gulch, with the intention of crosscutting the country to the Little Maggie vein. The project, however, was abandoned, and the tunnel was not accessible in 1900. Had it been completed it must have crossed the Blackhawk fault. The lowest tunnel of the Blackhawk enters in monzonite-porphyry on the southwest side of the Blackhawk vein, with a course of S. 73° E. Its position and course indicate that it might afford much information in regard to the fault, but the presence of gas prevented its entry in 1900.

It seems probable that the Little Maggie vein joins or is cut off on the northwest by the more nearly northwest fissures of the Blackhawk fault zone, and that the principal veins drifted on in the M and lower levels belong to this zone. Nevertheless, the Little Maggie should be cut somewhere in the northeasterly crosscuts on the M and Blacksmith levels. Several veins are intersected by these crosscuts, but none of them show the characteristics of the Little Maggie as known above the M level.

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[1] Cross and Spencer, loc. cit., p. 117.

Below the M level the main Blackhawk vein has a course of about N. 65° W. and consists of barren quartz up to 5 feet in width. The hanging wall is usually regular and separated from the vein by a slight gouge. On the Blacksmith level, two parallel veins about 40 feet apart have been drifted upon, but apparently contained little or no ore, although bunches of pyrite are not uncommon.

Practically all the ore from the lower part of the mine was derived from large replacement bodies in a bed of massive limestone near the top of the middle division of the Hermosa. This bed, which is estimated to be nearly 30 feet in thickness, dips away from the vein to the northeast, at an angle of 25° or 30°. It outcrops just east of the Bunkhouse level, exposing a large body of ore which has been extensively stoped. At this level the intersection of the ore body with the Blackhawk vein has been removed by erosion. The actual intersection of the ore-bearing limestone with the vein occurs just above the M level, where the Little Maggie oxidized ore stopped and the large bodies of sulphide replacement ore began.

These bodies of ore extend irregularly into the limestone to a maximum distance of 50 or 60 feet from the vein. They dip to the northeast, conforming to the dip of the limestone, and frequently attain a thickness of more than 15 feet. They are composed in great part of massive pyrite, of no present value, in which lie irregular bodies of workable ore. The best ore consists of fine-grained galena, chalcopyrite, sphalerite, and pyrite in a gangue of lilac and green fluorite. Such ore is often beautifully banded, the chalcopyrite and fluorite being disposed in thin concentric shells about centers irregularly grouped in the mass of ore as a whole. Ore of this character, being in large solid masses, with relatively little gangue, cleared about $10 per ton.

Such ore passes on its periphery into lower-grade ore, of which large quantities are still in the mine. This consists of massive, compact sphalerite and galena with a little chalcopyrite, and practically no gangue. It contains about 30 per cent of zinc, 20 per cent of lead, and up to 3 per cent of copper. This ore in turn sometimes grades into enormous masses of nearly pure pyrite, or is directly inclosed in limestone.

Near the Blackhawk vein the replacement ore bodies have a somewhat steeper dip and appear to turn up into the fissure. The ore, however, is not continuous with the material of the vein, the two being usually separated by a thin skin of gouge.

The upper portions of the large pyritic bodies are sometimes oxidized, and considerable cavities are formed by the solution and removal of the iron. Solution has also been active below the ore bodies, as shown in the M level, where the ore near the vein is underlain by a cavernous mass of rusty quartz, shown in Pl. XXVIII, *A*. This appears to have been formed by the removal of some soluble material, such as limestone or pyrite, from a network of quartz veinlets, and the subsequent deposition of fresh silica on the resulting skeleton.

As a rule there is no sharp wall between limestone and ore. The latter sometimes penetrates the white granular limestone in small irregular stringers and bunches, but more often the limestone next the ore is changed to jasperoid.

The limestone, and sometimes its included ore bodies, are cut by numerous fissures, some of which are small faults. In many cases these are mere gouge seams, obviously indicating movement since the ore was deposited. In other cases they contain quartz and pyrite, and were probably formed at substantially the same time as the main ore bodies. As a rule they have a general northwesterly course; but in the large stope east of the entrance to the Bunkhouse level a northeast fissure, carrying about three-quarters of an inch of banded quartz and ore, distinctly cuts the large ore body.

It is unavoidable that the foregoing description of the Blackhawk mine should leave many questions unanswered. The conditions are complex, and the opportunities for their investigation extremely limited. The existence of a great zone of faulting, from which several fissures, including the Little Maggie, branch off toward the southeast, has resulted in details of fissuring and fracturing which the present imperfectly mapped and unsystematic workings are wholly inadequate to unravel. But there is one clearly seen and important fact which vitally concerns the future of the mine. All the work on the replacement ore bodies has hitherto been confined to one bed of limestone at the top of the medial division of the Hermosa formation. But this entire division is composed chiefly of massive limestones aggregating several hundred feet in thickness. It is probable that the limestones below this upper bed, and extending down to Silver Creek on the northeast side of the Blackhawk fault, may also have been partly replaced by ore in the neighborhood of the fault zone. No effective prospecting has yet been done to determine whether ore bodies similar to those already mined may not exist in lower beds of limestone. Furthermore, the same limestones occur higher up Allyn Gulch and south of the Little Maggie shaft, on the southwest side of the Blackhawk fault. No attempt appears to have been made to determine whether these same Middle Hermosa limestones have been replaced by ore on this side of the Blackhawk fault zone.

ALLEGHANY MINE.

This lies northeast of the Blackhawk fault zone, and has been opened by two tunnels, the lower at 10,200 feet, and the upper at 10,300 feet in altitude. The vein strikes N. 70° W. and dips southwest at 72°. Like the Little Maggie vein it diverges to the southeast from the Blackhawk fault; but, unlike that vein, its southwesterly dip makes the divergence much more apparent on the surface. The workings are all in arkose sandstones and thin limestones of the Upper Hermosa, which the fissure does not appreciably fault.

In the upper tunnel the vein divides, one branch striking due southeast, a course which, if continued, must carry it into the Little Maggie vein.

The vein is filled with soft, oxidized silver ore up to 18 inches in width, which shows almost no quartz. It is said to have produced some argentiferous galena, but none was seen at the time of visit. It has been stoped between the two tunnels and above the southwest branch in the upper tunnel. The mine is at present idle and only partly accessible.

LEILA DAVIS MINE.

This lies immediately southeast of the Alleghany mine and on the easterly branch of the same vein. The main tunnel enters at an elevation of about 10,450 feet, while a second tunnel has been driven at 10,600 feet, and a third tunnel about 50 feet above the last. The vein strikes about N. 60° W. and dips southwest at 75°. The country rock is chiefly arkose sandstone in massive beds, part of which belong to the Upper Hermosa and part to the Rico formation, as mapped by Cross and Spencer. The vein filling is in all respects similar to that in the Alleghany ground, and has been stoped for a horizontal distance of about 300 feet and through a vertical distance of over 200 feet.

Owing to their opposing dips, the Alleghany-Leila Davis and Little Maggie veins may come together before reaching the ore-bearing limestone of the Middle Hermosa.

PRIVATEER MINE.

This is a prospect on the north side of Allyn Gulch, about 13,000 feet southeast of the Little Maggie shaft. It consists of a tunnel several hundred feet in length on a vein striking N. 70° W. and dipping northeast at 85°. This vein is in places 4 feet wide, but for most of the distance exposed is composed of crushed rock and gouge with but little quartz. The tunnel is partly in sandstone belonging to the Dolores and partly in an intrusive sheet of porphyry. The sandstones are not noticeably faulted by the fissure, although the abundant gouge shows that some movement has taken place along it. A little sphalerite and galena occur in the vein, but apparently no workable ore. The prospect is of interest on account of its proximity to the line of the Blackhawk fault, from which its vein appears to diverge in a manner similar to those of the Alleghany and Little Maggie mines.

ARGENTINE MINE.

This mine, situated in the bed of Silver Creek, on the line of the Blackhawk fault, was formerly worked through a shaft which is now abandoned and filled with water. There are also a few short tunnels on the south side of the creek, partly in a recent deposit of fragments of country rock from the hillside above, cemented by iron oxide.

The dump of the Argentine shaft shows limestone and sandstone as the prevailing country rocks. Coarsely crystalline pyrite is very abundant, and apparently occurred as a replacement mass in limestone, similar to that in the Blackhawk mine. It is reported by Gladford Smith, who last worked the mine, that the Blackhawk fissure runs through the shaft, but the ore occurs in another vein, trending northwest toward the Iron mine. This vein may coincide with the Last Chance fault, which is mapped by Cross and Spencer as passing near the Argentine shaft. The ore is said to have been about 3 feet wide and of low grade.

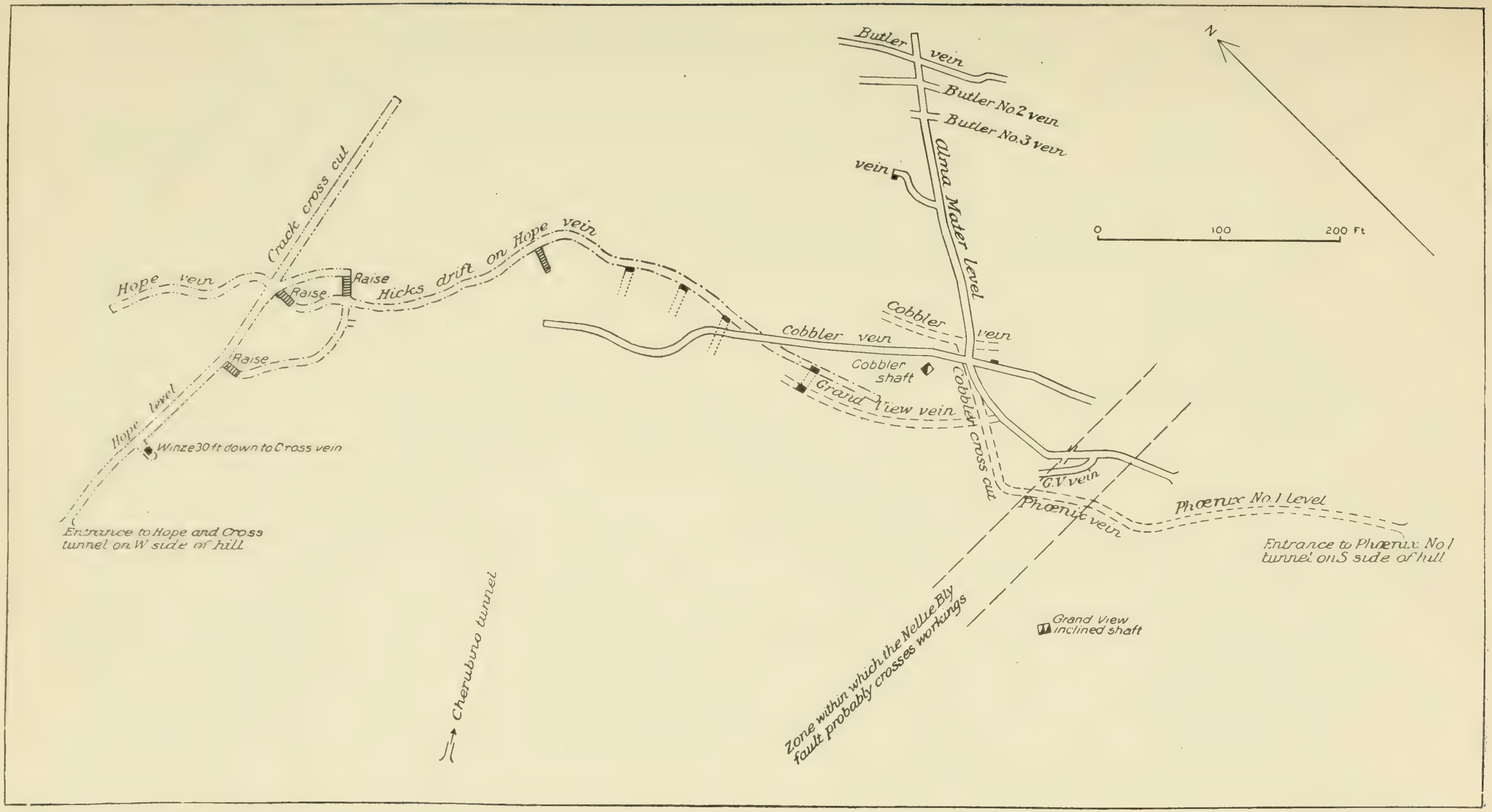
The country rock at the collar of the shaft belongs near the base of the Upper Hermosa; but the shaft undoubtedly penetrates the massive limestones of the medial division of the Hermosa formation.

UNCLE NED MINE.

This is situated in Uncle Ned draw, on the southwest spur of Telescope Mountain, in sandstones and shales of the Dolores formation. It is apparently on the Blackhawk fault fissure, but the workings are no longer accessible. The dumps show great quantities of quartz and pyrite, with a little sphalerite and galena.

WORLD'S FAIR MINE.

The workings of this mine lie just east of the Uncle Ned, on a vein striking N. 25° W., and thus diverging toward the north from the Blackhawk fault. The general dip is northwest at 75°. The vein, which has been opened by three tunnels, is oxidized and decomposed, and is accompanied by some gouge. It closely resembles the Little Maggie vein in general appearance, and has produced some silver-lead ore, but is now abandoned.



SKETCH PLAN OF A PORTION OF THE UNDERGROUND WORKINGS OF THE HOPE AND CROSS, PHŒNIX, AND ALMA MATER MINES, NIGGER BABY HILL.

MINES OF NIGGER BABY HILL.

GENERAL.

This hill was the scene of much of the early mining activity of the district. The ground is covered with claims which have been repeatedly abandoned and relocated, causing much confusion of names, and the hill is honeycombed with disused workings. Only a few of the more important of the latter will be described in the following pages, and no attempt will be made to adhere closely to the artificial divisions arising from individual ownership of various portions of this complex network.

GRAND VIEW GROUP.

This comprises the Grand View, Phœnix, Yellow Jacket, Major, and Pelican claims, covering some of the earliest locations in the district. These claims lie on the main spur and south slope of Nigger Baby Hill, ranging in altitude from about 10,050 feet at the old Cobbler shaft, on the nose of the hill, down to about 9,600 feet at the fourth level of the Phœnix workings, on the slope north of Silver Creek. They lie largely within the block of Middle and Lower Hermosa beds, which is bounded by the Nellie Bly fault on the north and the Last Chance fault on the south. Within this area the extensive workings have revealed numerous veins having general courses varying from N. 25° to N. 60° W. and dipping northeast at angles of 15° or 20° to vertical. The great number of these veins, the thorough oxidation and decomposition of their upper portions, the unsatisfactory outcrops, and the numerous faults which Cross and Spencer have shown to traverse the hill, render the study of these ore deposits exceedingly difficult. The former workings, moreover, were very poorly mapped and are now abandoned. Some of them are entirely inaccessible.

In 1900 the only way of examining the upper portions of the workings, including the old stopes, was by passing through the abandoned and caving drifts and inclines which connect the Phœnix No. 1 and Hope and Cross tunnels (Pl. XXXIX). The condition of these old workings was such that it was deemed prudent to confine their study to a single trip through them.

If accurate maps of all the Nigger Baby Hill workings were available and could be plotted on one sheet to the same scale, much light would undoubtedly be thrown on the perplexing problems presented by these veins; but the data for such a procedure are unfortunately not obtainable.

Three important veins have been worked in the Grand View mines. These are the Phœnix, Grand View, and Cobbler veins. They have a common strike of about N. 30° W. and on the Phœnix No. 1 level, where all three veins are exposed, something over 200 feet below the surface, they are about 50 feet apart. The Cobbler vein was originally worked from a shaft sunk on the summit of Nigger Baby Hill at an elevation of 10,060 feet. Near the surface the vein dipped northeasterly, but at the Phœnix No. 1 level it is vertical. This vein is small, but produced some excellent oxidized ore, and was continuously stoped from the surface down to the Phœnix No. 1 level (see fig. 67). At this depth the vein has a northeasterly dip of 80°, but is less steep in the Alma Mater level above, especially when followed northward. On the Phœnix No. 1 (Grand View No. 4) level the vein shows a width of about 8 inches in massive sandstones and a little shale. The vein is composed of an impure calcite associated with an abundance of the oxides of manganese and iron, and containing little vugs and druses of white calcite. It contains practically no workable ore at this level, and presents a condition intermediate between the thoroughly oxidized ore above and an unoxidized vein filling composed of low-grade sulphide ore in a calcite gangue.

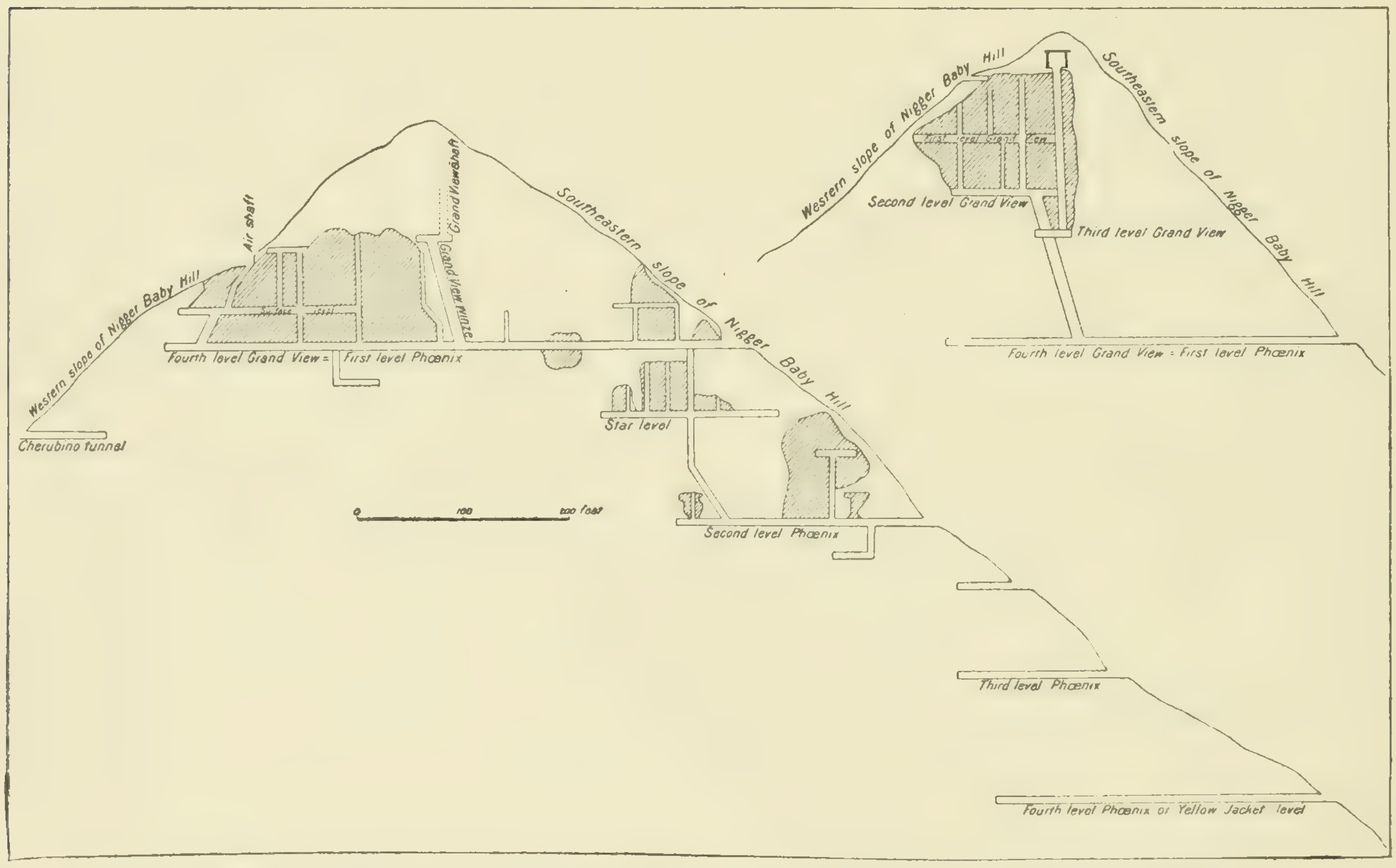

Western slope of Nigger Baby Hill
Air shaft
Grand View shaft
Grand View winze
Southeastern slope of Nigger Baby Hill
Fourth level Grand View = First level Phœnix
Cherubino tunnel
Star level
0 100 200 feet
Second level Phœnix
Third level Phœnix
Fourth level Phœnix or Yellow Jacket level
Western slope of Nigger Baby Hill
Southeastern slope of Nigger Baby Hill
Second level Grand View
Third level Grand View
Fourth level Grand View = First level Phœnix

FIG. 67.—Longitudinal sections through the Grand View and Phœnix veins.

At the southeastern end of the drift on the Cobbler vein are two cross fissures, striking N. 60° E. and dipping northwest at from 40° to 65°. These fissures are filled with soft gouge and are younger than the Cobbler vein; but they do not appear to fault it. In this end of the drift are massive limestones, presumably belonging to the Middle Hermosa, and some intrusive masses of porphyry. The presence of the limestone suggests that the Nellie Bly fault may cross this drift, but the exact location of the fissure could not be discovered.

The Grand View vein, on this level, lies 50 or 60 feet southwest of the Cobbler. It was formerly worked through the Grand View inclined shaft, which entered the hill at an elevation of about 10,000 feet in massive limestones, belonging to the middle division of the Hermosa formation, and followed down the dip of the vein. Somewhere in its course it is supposed to have passed through the Nellie Bly fault,[1] but as the shaft is timbered up, the rocks which it penetrates are not exposed on the Phœnix and Hicks levels (Pl. XXXIX), and in the stopes between them the Grand View vein (known as the Hope vein in the Hope and Cross workings) shows a variable dip up to 60°. When the dip is steep, the vein is small and cuts across the beds of shale and sandstone belonging probably to the Upper Hermosa. But where the dip flattens, as it does some distance above this level, and above the Hicks drift to the northwest, the vein is larger, and often follows the bedding planes for some distance. In such cases it may be 18 inches wide. It is composed of soft, oxidized material containing much oxide of manganese. Above the Phœnix No. 1 level this material was usually rich in silver.

The Phœnix vein lies about 50 feet southwest of the Grand View and is parallel to the latter in strike. At the Cobbler crosscut, the Phœnix vein dips northeast at only 15° or 20° and follows a bed of decomposed shale, about a foot thick, lying between relatively massive beds of sandstone. The vein, steepening its dip in places, carried soft oxidized ore from the Phœnix No. 1 level out to the surface, and has been extensively stoped.

South of the Cobbler crosscut the Phœnix No. 1 level follows a nearly vertical vein carrying partly oxidized galena in a decomposed gangue of impure calcite. This vein has the same strike as the flatly dipping Phœnix vein, and does not appear to fault the latter. It is probably merely a branch of the Phœnix fissure.

About 100 (?) feet south of the Cobbler crosscut the hanging wall of the Phœnix vein changes to massive limestone. The vertical fissure apparently turns abruptly to the west at this point, but the Phœnix vein, dipping 25° or 30° to the northeast, continues toward the mouth of the tunnel. Much good ore was stoped beneath the limestone in this part of the vein.

The Grand View vein has apparently not been worked below the Phœnix No. 1 level, but the Phœnix vein has been extensively stoped for an additional depth of over 150 feet down to the Phœnix No. 2 level. Between the Phœnix No. 1 and Star levels (see fig. 67) the general dip of the vein is 30°. The ore removed was soft, oxidized material, and appears to have frequently had a width of 4 or 5 feet. It lay between walls of fine-grained, massive sandstone.

A crosscut toward the southwest, and therefore into the foot wall, shows numerous veins of steeper dip than the Phœnix, which probably run into the latter above. These vary in strike from N. 45° W.

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[1] Cross and Spencer, loc. cit., p. 118.

to N. 80° W., and in dip from 50° to 85° to the northeast. These veins are composed of the soft, black, manganiferous material so common as a vein filling in the upper portion of Nigger Baby Hill. They traverse massive limestones and sandstones probably belonging to the Hermosa formation.

Below the Star level the Phœnix vein is less thoroughly oxidized. The old stopes show that the vein frequently pinched to a width of only 2 or 3 inches. In these narrow portions the ore consists of galena, partly changed to cerussite, with some sphalerite and pyrite, but practically no gangue. This ore lies between a hanging wall of sandy shale and a foot wall of fine-grained sandstone, and follows the bedding for some distance. Judging from the character of the stopes, the value of the ore was to some extent proportional to the degree of its oxidation.

On the Phœnix No. 2 level the country rock, consisting chiefly of massive sandstones of the Hermosa formation, is traversed by three steeply dipping veins. One strikes N. 70° W. and has a variable but generally vertical dip. It is very irregular, containing a little pyrite and oxidized material, but no ore. A second vein strikes N. 60° W. and dips northeast at about 70°. This carries pyrite, sphalerite, and chalcopyrite, and is in places 2 feet wide; but the ore is apparently of too low grade to extract. From the southwest side of this vein a flatter vein, dipping 40° to the northeast, branches just above the level. This vein carries a little galena ore and has been stoped. It is possibly the Phœnix vein, but the old stopes, in which alone the identity could be established, were not accessible at the time of visit.

The third nearly vertical vein is cut near the mouth of the level. It strikes N. 80° W. and dips southwest at 60°. Its filling is barren quartz about 6 inches wide. The dip and filling of this vein are different from those usually observed on Nigger Baby Hill. It is poorly exposed, and its relation to the other veins on the level is not apparent.

On the third level of the Phœnix the main drift follows a small, solid, unoxidized vein containing much sphalerite in a calcite gangue. This vein strikes N. 55° W. and dips northeast at 60°. An incline that was run up on the fissure for about 40 feet shows that this vein, which is beautifully banded, diminishes in width, lessens its dip to 35°, and finally breaks up into a network of small stringers in fine-grained Hermosa sandstone. From the top of this incline an inclined crosscut was run into the hanging wall for about 20 feet. This opened up a second generally parallel vein striking N. 60° W. and dipping northeast at 45°. This is a solid vein, containing abundant low-grade sphaleritic silver-lead ore in a calcite gangue. It has been stoped to some extent, and the workings extend up to the Phœnix No. 2 level, showing that it is probably the Phœnix vein. On the main No. 3

level this vein has decreased in width. It probably dies out, as the overlapping vein a few feet southwest of it grows larger. A winze on the latter vein shows that it, and not the original Phœnix, is the vein followed in the Phœnix No. 4 level.

The No. 3 level ends in a crosscut running N. 30° E. The breast of this crosscut is in massive crinoidal limestone of the Middle Hermosa, resting upon sandstone. The dip of the beds is 35° to the northeast. The veins on this level appear to follow the bedding planes in the main.

The fourth and lower level of the Phœnix mine is caved and inaccessible. Apparently several veins similar to those just described were prospected, but the ore was too poor to pay for working.

ALMA MATER MINE.

The principal level of this mine is shown in Pl. XXXIX. Lying about 50 feet above the Phœnix No. 1 level, it connects with the Grand View workings through the Cobbler vein, and on the east with the Butler mine. Probably nowhere at present accessible in Nigger Baby Hill can a better idea be obtained of the number of northwesterly veins which traverse the hill than in the Alma Mater level. It is essentially a northeasterly crosscut, connecting with drifts on at least six veins. The Nellie Bly fault is supposed to cross the tunnel about 75 feet from its mouth,[1] but the ground in this vicinity does not permit the certain identification of the fault fissure. There is much oxidation and decomposition and several irregular seams of gouge at this point, apparently connected with the Grand View vein. Beyond the Grand View vein the rocks are chiefly sandstones, frequently somewhat shaly, belonging probably to the Upper Hermosa beds.

The Cobbler vein, as seen on this level, is a nearly vertical sheeted zone in sandstone, containing streaks of oxidized ore up to 1 foot wide. It has been extensively stoped.

Between the Cobbler vein and the Butler group of veins, at least four veins, ranging in strike from N. 25° W. to N. 45° W., and dipping northeast, are cut by the crosscut. Upon one only has any work been done. The filling of these veins is rather fine-granular impure calcite, containing minute specks of sulphide ore, and more or less thoroughly decomposed to the soft, black manganiferous material already described. In hand specimens the undecomposed vein filling shows slight banding parallel to the fissure walls, but in thin section, under the microscope, can not be distinguished from an ordinary limestone slightly mineralized. The microscope shows that the alteration extends irregularly into the calcite as minute dark specks and dendritic patches, which become more closely aggregated as the change proceeds, until the calcite is all removed and a pulverulent black mass, largely oxide of manganese, remains.

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[1] Cross and Spencer, loc. cit., p. 118.

The Butler group consists of three parallel veins about 25 feet apart. The one nearest the mouth of the tunnel is known as the Butler No. 3, or Little Butler vein. It has been stoped, and is said to connect with the workings of the Butler mine, to the southeast. But practically nothing of the vein could be seen at the time of visit.

Northeast of the Butler No. 3 lies the Butler No. 2 vein, striking N. 25° W. and dipping northeast at 65°. This is a solid "spar" vein, 8 inches wide, showing almost no oxidation, and containing abundant sphalerite and a little pyrite and galena in a gangue of calcite. Much of the calcite is slightly pink, and probably contains manganese carbonate.

Northeast of the Butler No. 2 is the Butler vein, striking N. 30° W. and dipping northeast at 70°. This is similar to the preceding, but more oxidized. Considerable work has been done on this vein and some ore was extracted.

HOPE AND CROSS MINE.

This mine was probably the first on Nigger Baby Hill to produce ore in commercial quantities. It was originally worked in 1882 and 1883 by inclined shafts. It is now opened by a tunnel, situated on the western slope of the hill at an altitude of about 9,850 feet. The workings from this tunnel are continuous with those of the Grand View group (see Pl. XXXIX). Two nearly parallel veins are recognized, striking about N. 30° W. and dipping at low angles into the hill to the northeast. The upper and more easterly of these veins is the Hope, which is the same as the Grand View vein, as shown by continuous drifting. The dip of this vein is very variable. It frequently follows the bedding of the shaly sandstones for some distance, with a dip of about 20°, and then turns up across the beds with dips as high as 45°. It is filled with soft, decomposed material, much of which, being rich in silver, has been stoped out.

The Cross vein lies southwest of and below the Hope, the distance between them being about 45 feet. This vein is below the tunnel level, and is cut at the bottom of the winze shown in Pl. XXXIX. It shows much disturbance at this point, and consists of a streak of decomposed rock, clay, and black oxide of manganese, underlain by decomposed sandstone, which is shattered to a distance of 2 or 3 feet from the vein. The hanging wall is a micaceous sandy shale, also much disturbed. The best and most abundant ore is found in the flatter portions of the vein. It is distinguished from the worthless oxidized material by the presence of specks of copper carbonate. The maximum thickness of the ore is 3 feet, but the usual thickness is from 4 to 8 inches. It contains on an average from 150 to 300 ounces of silver per ton, although some ore running as high as 1,300 ounces per ton has been shipped.

In its position with reference to the Hope or Grand View vein, the Cross vein corresponds to the Phœnix. It would be unsafe, however, to assume their identity in a locality where fissures of like trend are so numerous, and where there has evidently been so much disturbance.

A little north of the Hope and Cross tunnel, and 96 feet vertically below it, a tunnel has been run to cut the Cross vein at a more convenient point for working it. About 250 feet from its mouth it cuts a strong fissure striking N. 40° W. and dipping at 45° or 50° to the northeast. It is from a foot to 18 inches wide and very regular. It contains some crushed quartz, clay, oxide of manganese, and gouge next the walls. But although much drifting has been done along this fissure, upon the supposition of its being the Cross vein, only traces of ore have been found. It seems probable that the foregoing supposition (now abandoned by the prospectors) is correct, in spite of the lack of ore, and that this fissure is continuous with that known as the Cross vein in the upper workings. But, as is often the case in prospecting, a little accurate surveying is the last resort, rather than the first preparation.

Scattered thickly over the hillside between the Hope and Cross and Grand View adits are a number of little tunnels, from some of which rich ore was being shipped in 1900. They lie to the north of Nellie Bly fault, in sandstones and shales of the Upper Hermosa, which, at the fault, are brought into juxtaposition on the south with massive limestones of the Middle Hermosa.

With the exception of a small stringer of galena, all the ore is of the usual oxidized character and comes from the superficial portions of the Cobbler, Grand View, or Hope, Cross, and other veins. One lot of about 20 tons, shipped in 1900, was valued at about $2.50 per ton. Most of these workings are too shallow and irregular to merit special description.

NELLIE BLY MINE.

The chief interest of this little mine is in connection with the great fault to which it has given its name. The workings consist of two tunnels on the south slope of the hill—one at an elevation of about 9,900 feet, and the other approximately 50 feet below it. The two are connected by a winze. The lower tunnel, shown in fig. 68, is a crosscut through shales, sandstones, and intrusive porphyry, and in 1900 was being extended with the object of tapping the Butler veins. About 125 feet from its mouth the tunnel cuts an east-west fissure, dipping north at 85°. This fissure is only 3 or 4 inches wide, and is filled with tightly squeezed crushed rock. It is probably the Nellie

Bly fault, although the shales on each side of the fissure at this point are apparently identical. A vertical upraise on this fissure finally opened up the Nellie Bly vein, presumably at the intersection of the latter with the fault plane.

The work of the Nellie Bly vein is all on the level of the upper tunnel. This enters in massive gray limestone belonging to the medial division of the Hermosa formation. But about 6 feet from the mouth the limestone is cut off by a fault and the tunnel passes into fine-grained shaly sandstones belonging to the upper division of the Hermosa. The fault strikes north 75° east, and dips north at 80°. The fissure is clean cut, about 4 inches wide, and filled with firmly squeezed crushed rock. The only trace of mineralization consists of slight staining by oxide of iron. There can not be much reasonable doubt but that this fissure is identical with that noted in the lower tunnel, and is the Nellie Bly fault as supposed by Cross and Spencer. The throw as observed at the Nellie Bly is certainly over 6 feet, and is probably many times this amount. These writers, however, sometimes speak of the fault as if it were synonymous with the Nellie Bly vein. This is a misapprehension.

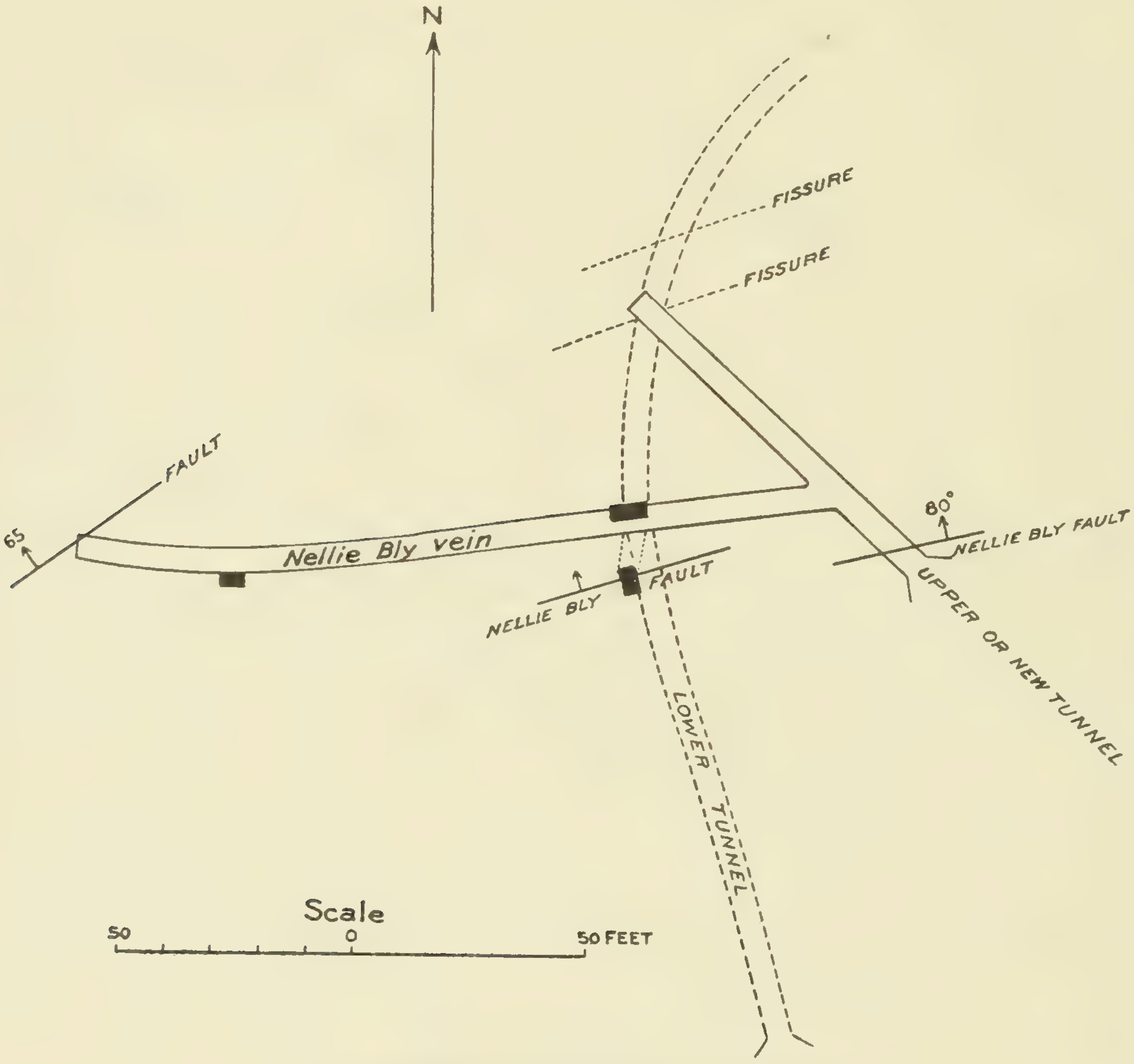

FIG. 68.—Sketch plan of the Nellie Bly mine.

The Nellie Bly vein, which closely resembles the Grand View vein, and may possibly be identical with it, has a strike generally parallel to that of the fault fissure, and, on the level of the tunnel, is separated from the latter by about 20 feet (fig. 68). The Nellie Bly vein dips north at from 40° to 55°. The Nellie Bly fault is nearly vertical. The two probably intersect in the stopes above the level, and this led to the discovery of the vein through a raise started originally on the fault from below. The footwall of the Nellie Bly vein is porphyry, the hanging wall, sandstones, and shales dipping north at 20° or 25°. The vein and its porphyry footwall, having a steeper dip, cut these beds at a small angle, although thin seams of vein matter often extend out in the planes of bedding toward the north.

The vein matter of the Nellie Bly is composed chiefly of the sooty alteration product common in the veins of Nigger Baby Hill, with sometimes a little white "sugar" quartz and irregular masses of fine-grained yellowish calcite. A chemical analysis of some of this vein-filling is given on page 267. The particular sample analyzed came from a portion of the vein not regarded as ore, but it illustrates well the general nature of the material so characteristic of the upper portions of the Nigger Baby Hill veins. In some of the stopes above the level the vein has a width of 2 to 3 feet, consisting of the above material traversed by broken stringers of quartz and containing residual nodules of impure calcite. In some places, where alteration has been complete, the calcite or "spar" is 5 feet in width.

The Nellie Bly vein was drifted on and stoped for a distance of about 160 feet from the tunnel to a point where it is cut off on the west by a fault striking N. 55° E. and dipping northwest at 65°. The fault fissure contains soft, yellow clay gouge between broken and slickensided walls. The Nellie Bly vein is sharply deflected or dragged to the south at the intersection with the fault.

The product of the Nellie Bly vein is reported to have amounted to about $8,000. The main tunnel on this level follows a small partly oxidized "spar" vein, dipping southwest at 85°. The country rock shown is sandstone, apparently dipping north at 25°. A little ore was taken from this vein in a raise near the breast.

IRON MINE.

This mine, located in 1882, lies on the southeastern slope of Nigger Baby Hill, the main adit being a tunnel at a little over 9,300 feet in altitude. This tunnel is between 800 and 900 feet in length, and with the exception of a crosscut of about 75 feet near its mouth, follows a vein striking N. 16° W. and dipping easterly at from 60° to 85°. This vein can be traced on the surface, up the ravine above the mine, to the saddle behind Nigger Baby Hill in which is the Bourbon prospect on the same fissure.

The country rock exposed in the main tunnel consists of sandstones, limestones, and shales. For a little over half its length the tunnel is in beds belonging to the middle division of the Hermosa formation, including several strata of limestone. But for a distance about 400 feet outward from the breast, sandstones and firm shales are the only rocks met with. These probably belong to the upper division of the Hermosa. This change from one set of beds to another is probably due to the Nellie Bly fault, which, as mapped by Cross and Spencer on the surface, must pass through the tunnel. Careful search for this fault, underground, failed to satisfactorily demonstrate its presence. But it is believed that the accompanying partly diagrammatic section (fig. 69) represents the most reasonable interpretation of the observed facts.

About 450 feet from the mouth, the tunnel passes through a bed of limestone containing crinoid stems and evidently belonging to the lower division of the Hermosa. This bed and the sandstones underlying it dip north at about 50°, flattening somewhat above the tunnel. The limestone is succeeded on the north by sandstones and shales of much lower dip—only 20°. Between the limestone and the bed of sandstone just north of it is a vein of crushed banded quartz about 4 inches wide, which probably fills the Nellie Bly fault fissure. Owing, however, to the similarity in dip between the fault and limestone at this point, and the fact that the limestone is overlain by sandstone similar to that brought into juxtaposition with it by the fault, it is impossible, in so limited an exposure, to be certain that the vein really traverses the beds, instead of lying between them.

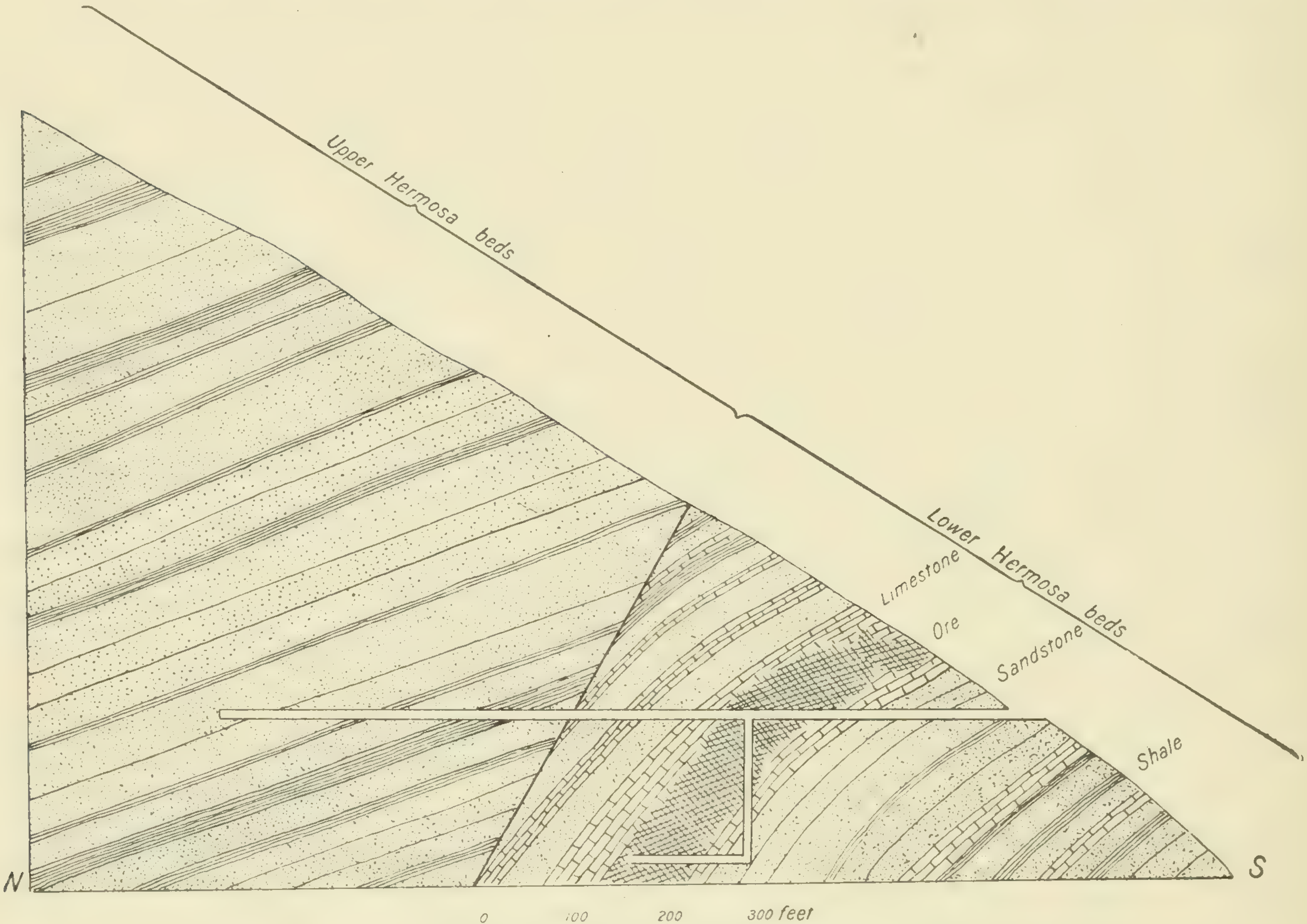

FIG. 69.—Diagrammatic longitudinal section through the Iron mine.

The Iron vein is not appreciably dislocated by the fault. Near the mouth of the tunnel, in sandstone, the vein is over 5 feet wide and consists of two portions. Next to the hanging wall is a fairly solid mass of banded quartz from 4 to 10 inches wide. The rest of the vein consists of disturbed quartz and country rock. Beyond the fault the vein is usually smaller. Calcite is a common gangue mineral throughout and at the breast is particularly abundant. It contains much sphalerite and some pyrite, and has a faint pinkish tint, suggesting the presence of a little manganese. It resembles the material found in the Butler No. 2 vein on the Alma Mater level (p. 380). With the exception of a pocket of tetrahedrite ore, found about 40 feet above the tunnel and 360 feet from the breast, the Iron vein proper contains practically no ore where shales or sandstones form the country rock. But where the fissure traverses the limestone beds of the Middle Hermosa formation these are replaced by ore to a width of from 6 to 12 feet. The main ore body is over 100 feet in length and occurs in the largest bed of limestone cut in the tunnel (see fig. 69). This ore was stoped upward, on the dip of the bed, to the surface. It was followed down by a vertical winze 150 feet deep, which, owing to the northward dip of the limestone, ran through the bottom of the ore. The latter was recovered by drifting north from the bottom of the winze. Ore was also found extending into the limestone for some distance from the vein, following fissures which dip about 40° to the southwest and come to the main vein from the northeast. The ore is usually massive, consisting chiefly of pyrite and chalcopyrite, in a calcite and quartz gangue. A little galena is sometimes present. The material stoped contained from 40 to 70 ounces of silver per ton, 2 or 3 per cent of copper, and 30 per cent of iron.

Owing partly to the fact that the main ore body can no longer be cheaply worked from the tunnel level the mine is now idle. The winze was filled with water at the time of visit, so that nothing could be seen of the ore body below the tunnel level. It probably follows the bed of limestone down to a considerable depth, until perhaps ultimately cut off by the Nellie Bly fault.

LAST CHANCE MINE.

This is a prospect situated on the trail, about 800 feet southwest of the Iron mine. It consists of a tunnel about 200 feet long on a fissure having an average course of N. 80° W. and nearly vertical. This fissure contains a strong but variable vein composed of quartz, pyrite, and a little chalcopyrite. It differs from the other lodes of Nigger Baby Hill, but its chief interest is connected with the statement of Cross and Spencer,[1] that it corresponds to the Last Chance fault, which brings up Algonkian quartzite on the south against monzonite-porphyry on the north. The actual fault may be parallel with the vein, and is certainly very close to it. But the walls of the vein fissure are both porphyry, much altered and impregnated with pyrite. It is probable that the porphyry on the south wall is a thin skin only, separating the vein from the actual fault plane.

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[1] Loc. cit., p. 119.

MINES OF C. H. C. HILL.

GENERAL.

That portion of the western slope of Telescope Mountain known as C. H. C. Hill is practically coextensive with the large landslide mass which covers the slope from an altitude of about 11,750 feet on the east down to the Dolores River on the west, crowding the latter stream over against the base of Sandstone Mountain.[1] Like its neighbor, Nigger Baby Hill, C. H. C. Hill is penetrated by a labyrinth of workings, many of them extensive and most of them abandoned and inaccessible. The more important mines are owned and worked in groups, as follows:

Group.	Claim.
Wellington group	Wellington. Zona K. C. S. and H. H. Maid of Australia. Lottie.
Logan group	General Logan. General Sheridan. General Howard. General Sherman. Little Casper. Goliath.
C. H. C. group	C. H. C. Athlena. Limestone. Princeton.

The Crebec mine, closely connected with the Princeton, and the Pigeon mine, on the northwest portion of the hill, have also been important. The following descriptions will adhere to this grouping only so far as is convenient in a region of such irregular and interlacing workings. No good maps exist for any of the mines.

At the present time work is restricted to prospecting in the Wellington and Logan groups, the extraction of a little ore, by leasers, from the Princeton mine, and some development on various less important properties. It is exceedingly doubtful whether any of the ore taken from the C. H. C. hill has come from rock in place.

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[1] See Cross and Spencer, op. cit., pp. 136–141, for fuller account of this landslide area.

WELLINGTON GROUP.

The ore in this group occurs in a so-called "contact," or blanket zone. This was originally worked through the Wellington shaft, now abandoned. The main adit at present is the Mountain Spring tunnel, situated almost directly opposite the mouth of Horse Gulch, at an elevation of about 9,500 feet. This tunnel extends for 940 feet in a direction N. 75° E. For 210 feet it passes through loose surface detritus, and then enters sandstones and shales, generally badly shattered and disturbed. Where the bedding of these rocks is not obliterated they may be seen dipping at variable low angles to the southwest. But more often the beds are reduced to a chaotic jumble of large fragments, separated by clayey material. Two dikes of white quartzose porphyry and a few small stringers of quartz are intersected by the tunnel. These are all broken and displaced. Much of the sandstone in the tunnel is bleached nearly white by removal of the iron originally present in its constituents.

An upraise of 85 feet from the breast of the tunnel gives access to the Zona K. level, which is run beneath the main "contact" and connects with the Sheridan and Logan workings, and formerly connected with the Princeton and C. H. C. mines. The rocks exposed on this level are fine-grained, nearly white, noncalcareous sandstones and compact limestones. These are much fissured and faulted, but somewhat less disturbed than the rocks in the Mountain Spring tunnel. Little regularity can be recognized in these fissures. They are small irregular fractures, containing soft clay gouge, but no quartz. The general dip of the beds is from 10° to 30°, in a direction a little east of south.

Above the level, resting sometimes on a fine-grained, nearly white, micaceous sandstone and sometimes on limestone, is the "contact," composed chiefly of loosely cohering limonite and yellow clay up to 5 feet in thickness. It dips generally to the southwest, but is rolling and uneven, as well as variable in thickness. It is overlain by sandstone.

In the northeastern part of the workings the "contact" has risen, so that it lies just above the Sheridan level (really in ground belonging to the Logan group), which is 80 feet above the Zona K. level. It is here evidently a plane of faulting, being filled with fragments of sandstone, yellow and gray clay, and limonite. It is also traversed by seams of very tenacious soft gouge. This brecciated material passes with no sharp division into the overlying fractured sandstone, called by the miners "porphyry," or the "mineral roof." The thickness of the blanket zone ("contact") varies in this portion of the workings from 1 to 5 feet. The ore, when present, usually occurs in the lower portion in the form of argentiferous oxide and carbonate of lead. None, however, was seen at the time of visit.

At the northeast breast of the main Sheridan level the blanket zone lies 25 feet above the drift. It turns upward near this point, toward the southeast, following a very smooth but undulating slip plane. The general strike of this plane is northeast and southwest. The average dip is about 45° to the northwest. The blanket zone, where it follows this fissure, lies between two seams of clay gouge, and contains a little partly oxidized galena ore.

At a vertical distance of 25 feet above the Sheridan level lies a portion of the Logan level. This formerly connected with the Logan tunnel and shaft, but is now reached through the Wellington workings. It lies just north of the latter.

Portions of this level are run in the main "contact," here about 100 feet higher than where first described, above the Mountain Spring tunnel. This difference is partly due to a general southerly dip, but is said by those who worked in the old stopes, now caved in, to be in part due to successive step faults of small individual throw. Large bodies of pyrite occur in the "contact" on the Logan level, and it is without doubt from the oxidation of similar bodies that there has resulted the crumbling limonite so abundant in other portions of the "contact."

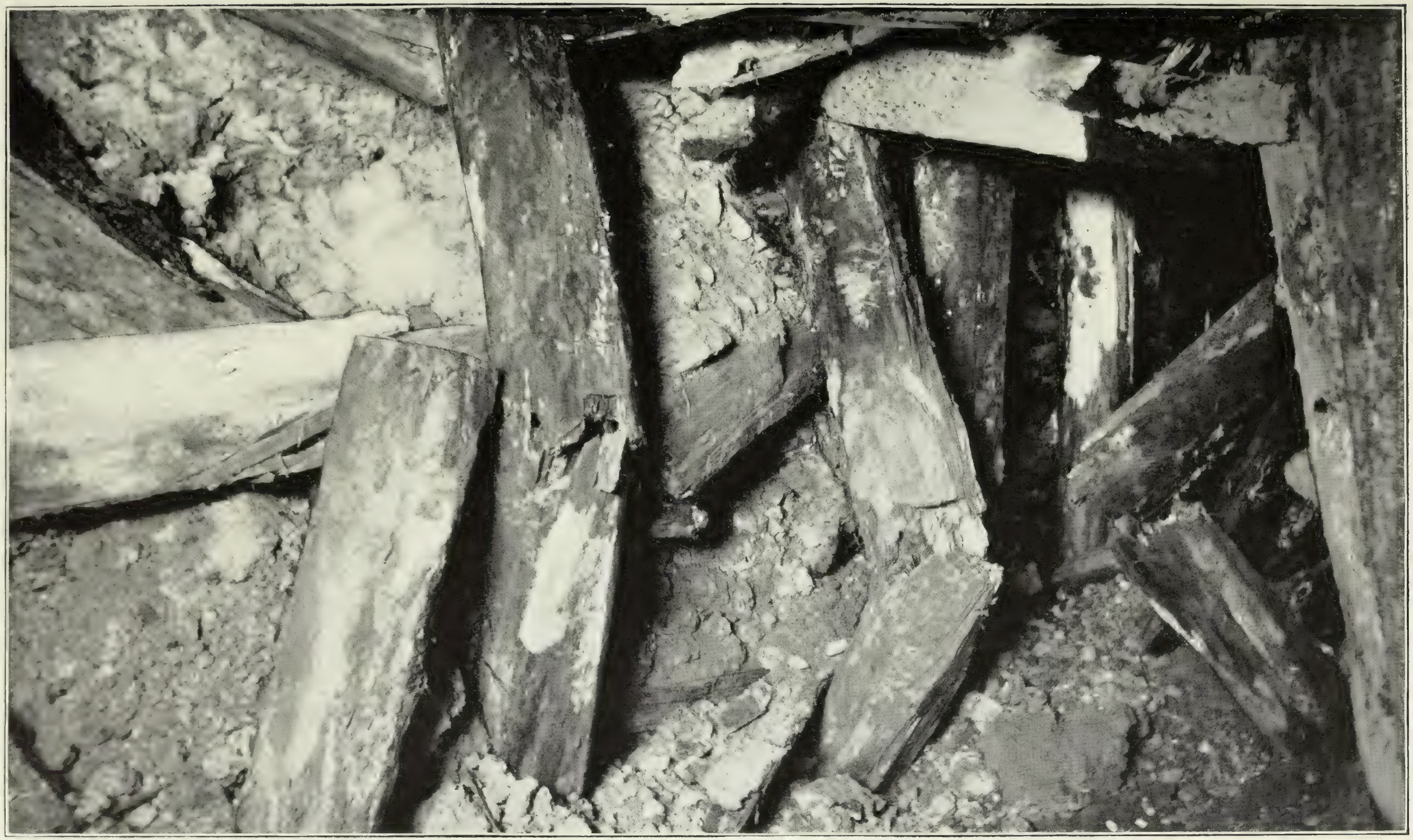
A crosscut to the northeast, near the old Logan shaft, cuts through 15 feet of loose crumbling pyrite into what is known as "the big fissure." This is an enormous lode of crushed quartz and pyrite, which will be more fully noticed in the newer Logan workings and in the Pigeon mine.

Owing to the lack of surface exposures and the great disturbance of the entire hill, it is difficult to determine the exact horizon of the sandstones, shales, and limestones met with in the Wellington mine. The difficulty is increased by the very prevalent bleaching and alteration of the sandstones, so that they resemble no beds found elsewhere in the region. It is believed, however, that they belong to the upper division of the Hermosa.

PRINCETON MINE.

These workings lie about 700 feet south of the Mountain Spring tunnel, and were formerly connected underground with those of the Wellington group. The Princeton ore occurred in a blanket, said to be continuous with that of the Wellington group. It was worked through an adit tunnel which enters the hill at an elevation of about 9,600 feet, and runs N. 61° E. for about 400 feet.

None of the old Princeton workings are now accessible. The landslide in which they lie is still creeping slowly down the slope, so that



DRIFT IN THE PRINCETON MINE, C. H. C. HILL.

Shows the result of movement in the landslide mass.

timbers originally set in an upright position are soon thrown out of plumb. The effect of this movement is speedily blocking abandoned drifts, is shown in Pl. XL, from a photograph taken by G. W. Tower, in 1898, near the end of the main tunnel. It illustrates well the difficulties attending the study of abandoned workings in the Rico region. This tunnel, and a long irregular drift to the Crebec shaft in the southeast corner of the mine, has since been reopened by leasers who, in 1900, were taking out a little ore containing 40 to 60 ounces of silver and considerable lead from the Crebec ground.

This ore occurs in a blanket said to be continuous with that formerly worked in the Princeton. Near the Crebec shaft the blanket, or "contact" as it is called, is about 50 feet from the tunnel level, but comes down to the latter near its mouth. The dip, while generally southwest, is very variable and the mass is minutely faulted by numerous small fractures. The blanket rests on hard, fine-grained shattered sandstone without any very sharp line of separation between the two. The sandstone is buff in color and noncalcareous. The quartz grains are held together by an abundant ocherous cement of uncertain character and probably of secondary origin. The blanket is overlain by gray shales, often much shattered.

The material composing the blanket varies from place to place. It sometimes consists of a cellular or loosely cohering mass of limonite 4 feet in thickness, containing fragments of sandstone and limestone. These are evidently in part residual masses; the limestone especially being surrounded by soft shells of decomposition or alteration. In other portions of the workings the lower one, to 3 feet of the blanket, consists of yellow, clayey material, near the top of which is a streak of a few inches of soft, ocherous ore containing a considerable amount of silver. Above this there is usually about 8 inches of soft, gray banded ore, commonly referred to as "carbonate ore." This, however, is a misnomer, as it contains no appreciable quantity of carbonates. It is in considerable part impure, pulverulent lead sulphate. Some of the bands are composed of a snowy-white substance, locally called "talc," which crumbles between the fingers to a fine harsh powder. A rough chemical examination of this material by Dr. Hillebrand shows it to contain about 83 per cent of silica, over 5 per cent of water, and about 9 per cent of lead sulphate. Under the microscope the powder is apparently amorphous. The silica is probably in the opaline form. In composition and physical properties it closely resembles tripolite or infusorial earth. But it shows no trace of organic structure, and is undoubtedly a product of chemical alteration connected with ore deposition.

Large lenticular bodies of iron pyrite occur at several horizons in the sandstones and shales above the blanket. Some of them are separated from the latter only by a few inches of crushed shale. But one of the largest masses occurs about 50 feet above the main blanket. An upraise in this mass shows it to be over 40 feet thick, although possibly divided into two or more lenses by layers of shale which were not visible in the timbered upraise. It rests on sandstone and is overlain by soft gray shales impregnated by pyrite. According to Mr. Gladford Smith, who sank the Crebec shaft, three flat bodies of pyrite aggregating over 50 feet in thickness and separated by shales were passed through. The depth of the shaft is 265 feet. The pyrite, which is nearly pure, occurs in loose, sandy form or in solid masses. It is of too low grade to work with the present facilities.

C. H. C. MINE.

This was one of the first mines worked on C. H. C. Hill, and produced considerable ore. The workings, which were relatively extensive, are now abandoned and so little accessible that no description of the mine is possible. The first workings were reached through a shaft, sunk about 900 feet north of the Princeton tunnel, at an altitude of 9,800 feet. The C. H. C. tunnel was subsequently run in about 100 feet lower down the hill, and much work was done on the Limestone tunnel, about 400 feet north of the Mountain Spring tunnel.

The ore occurred in a blanket, probably identical with that worked in the Wellington and Princeton mines.

LOGAN MINE.

This lies immediately north of the Wellington group. The first mining was done through the Logan shaft, sunk at an elevation of 9,950 feet, in a little ravine which appears to mark on the surface the location of the Blackhawk fault, familiarly known on C. H. C. Hill as the "big fissure." A second shaft was sunk about 200 feet lower down this ravine. Both are now abandoned, and the present adit is a tunnel, also in the ravine, entering at an elevation of 9,650 feet, a little above the Pigeon mine.

The accessible portions of the older workings, lying southeast of the Logan shaft, have been already described in connection with the Wellington mine, through which they are at present reached.

The Logan tunnel follows a general southeasterly course, connecting with the Logan No. 2 shaft, and continuing toward the Logan shaft. This course keeps it on the southwest side and nearly parallel to the so-called "big fissure," which is reached by some northeast crosscuts. One of these crosscuts about 100 feet southeast of the Logan No. 2 shaft shows that the "big fissure," which will be referred to as the Pigeon vein, on account of its prominence in the mine of that name, is a large quartz vein, 12 feet wide, consisting of white quartz and masses of crumbling pyrite. It is much broken up, and mingled with gouge and fragments of country rock. The vein dips northeast, apparently at from 45° to 50°. The hanging wall consists of dark, much broken, and partly decomposed shale. That this fissure is a fault of considerable throw is indicated by the cutting off of a dike of white porphyry, as shown in fig. 70. The amount and direction of throw, however, are not known.

The ore in the Logan tunnel occurs in two or more blankets between beds of sandstone and limestone. These present many variations in character. Near the Logan No. 2 shaft the main blanket lies between somewhat shaly, arkose sandstones. It is very irregular in dip, but conforms generally to the bedding of the inclosing rocks. It consists of limonite, either cellular or crumbling, with much soft, nearly white material, which passes with no sharp break into firm sandstone, of which it is plainly an altered form. The sandstone, which in surface exposures is usually greenish in color, is nearly white in the vicinity of the ore bodies, although irregularly streaked with iron oxide. Under the microscope it is seen to be composed chiefly of quartz and sericite. The sericite, in minutely crystalline aggregates, acts partly as a matrix for the quartz grains, and occurs also in patches, probably representing altered fragments of feldspars. Some larger scales of white mica are visible with the unaided eye. Chemical analyses of this sandstone and its alteration product are given on page 287, and the nature of the change which they indicate is there discussed.

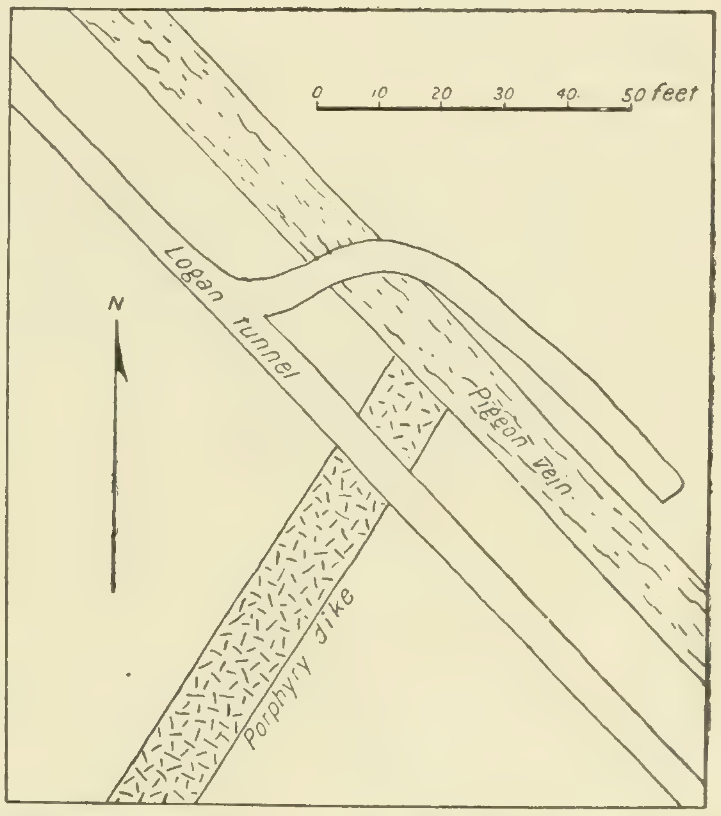


FIG. 70.—Diagram illustrating faulting of a porphyry dike by the Pigeon lode fissure in Logan mine.

Nearer to the Logan shaft the blanket, here from 3 to 4 feet thick, rests on limestone and is overlain by sandstone. The upper part of the blanket is derived from the overlying sandstone through the alteration just noted. The lower portion (a little less than one-half of the whole) is chiefly an ocherous or limonitic mass, which falls to a powder when dry, and is evidently in part formed at the expense of the limestone. It is roughly laminated and is concentric with the irregular upper surface of the underlying limestone. Between the ferruginous material and the limestone is a shell of soft, white material, which adheres to the limestone and constitutes a crust of alteration. This crust is minutely fissured, and the cracks are filled with a soft, black powder, probably manganiferous. The white crust adhering to the limestone is chiefly gypsum, as shown by chemical tests. Closely associated with this crust is another white substance, not at first distinguished from the compact white gypsum. This material proves to be halloysite. The halloysite is intimately associated with the ferruginous material above it, and is full of little specks and nests of soft, black oxide of manganese. The relations of these various materials are diagrammatically shown in fig. 71. The limonite material, especially near the Pigeon vein, is sometimes rich enough to work. Some was said to contain up to 3 ounces of gold and 30 ounces of silver per ton.

It is very probable that the so-called "main contact" of the Logan is the same as that worked in the Wellington, C. H. C., and Princeton mines. But it is certain that other similar, but less extensive zones occur in the Logan mine, both above and below the main one. They do not necessarily contain any workable ore. Nearly flat blankets of pyrite are frequently met with on the southwest side of the Pigeon vein, extending from the latter out into the bedding planes. This pyrite is of too low grade to work. At a varying distance from the Pigeon vein, it usually passes into the limonite material already described, which is sometimes valuable as ore.

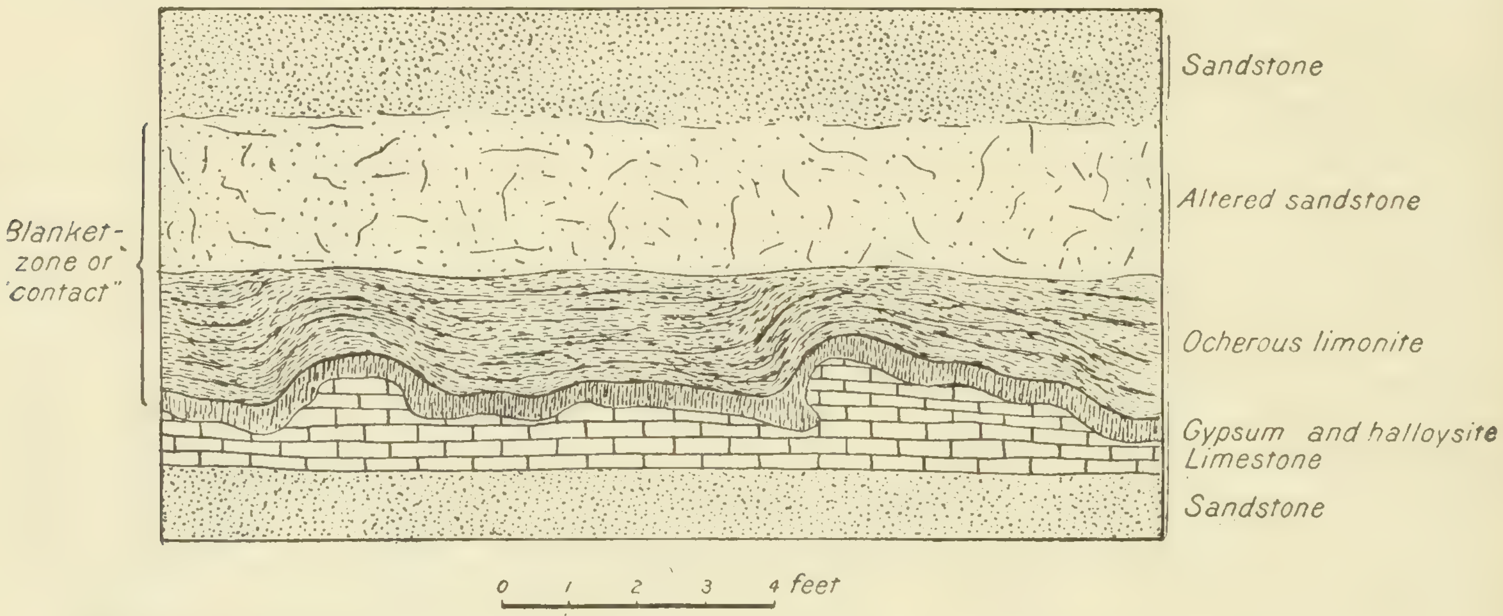


FIG. 71.—Diagrammatic section through a portion of the blanket zone of the Logan mine.

PIGEON MINE.

This mine, the most northerly of the important workings on C. H. C. Hill, lies northwest of and about 100 feet below the Logan tunnel. It was formerly worked through three tunnels and two shafts. The original Pigeon shaft, at an altitude of about 9,850 feet, lies about 600 feet west of the Logan shaft.

The lowest workings of the Pigeon consist of the Blaine and Logan tunnel, run at an elevation of about 9,300 feet. This penetrates sandstones and shales, which show far less disturbance than is usually found in C. H. C. Hill, and may possibly be in place. No ore has been shipped from this tunnel, although a little replacement ore in limestone was found at the bottom of a winze, 90 feet below the tunnel.

One branch of this lower tunnel cuts through the Pigeon lode, which shows a width of 40 feet. It is composed of several stringers of barren white quartz, separated by sheets of country rock, the whole being crushed and disturbed. The vein strikes about N. 50° W. and dips northeast at 75°. The foot wall is slightly shaly sandstone, decomposed to a soft, gray mass for a width of 3 feet.

Most of the Pigeon ore has come from the upper tunnels, about 200 feet above the Blaine and Logan tunnel. It occurs in a blanket, which, although encountered at a lower level than that of the Logan mine, may yet be identical with the latter. If so, it owes its lower position to faulting connected with landslide movement. The blanket is often 6 feet and sometimes as much as 12 feet. It varies greatly in character. In places it is a breccia of limestone and shale, the former being silicified and impregnated with pyrite. It frequently contains lenticular masses and streaks of crumbling iron pyrite, or bodies of more or less ocherous, limonitic ore. Sometimes there are streaks of soft, banded material resembling that described in the Princeton mine, and sometimes masses of white pulverized quartz (sugar quartz). The blanket is usually underlain by fine-grained sandstone or shale. It is apparently overlain by sandstone, although the roof is not well exposed. The blanket generally dips gently to the southwest, but shows many irregularities. At one point it was found to turn up toward the north at an angle of 55° for about 20 feet and then to resume its usual gentle dip.

The entire blanket shows evidence of much movement, and the inclosing rocks are broken and decomposed. Much work has been done on this ore zone, but apparently without very great success, as most of it contains only low-grade pyrite.

As in the Logan mine, ore is not confined to a single horizon. In what is known as the middle tunnel, a lode striking N. 45° W. is drifted on for some distance. It is probably the Pigeon lode, but is greatly broken and decomposed and not well exposed. Some ore occurred in the bedding planes on the southwest side of this fissure, and carried 8 or 10 ounces of silver and 18 per cent of lead. These were mere local lenses of oxidized ore which did not extend far from the main fissure. A specimen of some of the so-called "carbonate ore," a yellow ocherous powder, proved upon analysis to be chiefly jarosite, a hydrous sulphate of iron and potassium (see p. 289).

LILY D. MINE.

This is situated on the southwestern slope of C. H. C. Hill, the main adit being a tunnel at 9,150 feet in elevation. This tunnel runs N. 85° E. for 220 feet and then connects, through a raise of 80 feet, with some irregular workings exploiting two blankets. These zones, which are about 8 feet apart, have been faulted by a vein striking S. 80° E. and dipping N. 85°. The fissure is filled with crushed rock, quartz, and gouge, and carries no ore. Normal faulting to the extent of 12 feet throw, has taken place along this fissure, but whether before or after the deposition of the blanket ore, is not known.

The blanket contains masses of solid pyrite, cellular quartz, limonite, and streaks of partly oxidized sphalerite and galena ore. The lower blanket rests on sandstone and is overlain by shale. At one place, however, near the fault fissure, it dips southward at an angle of 35° and cuts across some of the bedding planes. The upper blanket lies in a brecciated zone in shale.

The ore contains about 20 per cent of sphalerite and is difficult to treat on that account.

As is usually the case on C. H. C. Hill, all the rocks in the workings are much broken. Their general dip is southerly at about 10°.

IRON GIANT MINE.

This is a prospect lying north of the Lily D. and about 50 feet higher up the hill. It consists of a tunnel about 500 feet in length, running N. 63° E. and cutting through shales and fine-grained, reddish, sandy limestone. These strata, which dip southwest at a slight angle, are all more or less shattered, in the usual manner. Two or more so-called "contacts"—i. e., zones of soft, crushed material, sometimes containing pyrite, are cut in the tunnel. These zones conform to the bedding, but do not preserve their continuity far, being cut off by fractures filled with gouge or crushed rock.

The chief interest of this prospect is derived from the fact that after cutting through nearly 500 feet of the usual disturbed rock of C. H. C. Hill, the tunnel has come into a mass of old surficial gravels, 250 feet vertically below the surface, proving conclusively (were any such proof needed) the landslide character of the material covering C. H. C. Hill. These gravels consist of partially rounded gravel and sand. Some bowlders occur up to 300 pounds in weight, and those a foot in diameter are not uncommon. Most of the material, however, is finer. The small pebbles are usually well rounded, while the larger ones are subangular. The most abundant pebbles are those composed of fine-grained red sandstone; others are of gray sandstone, monzonite, or diorite-porphyry, white quartzose porphyry, shale, white limestone, and quartz. One pebble of galena was found. All of the material is oxidized, and the resulting yellow color is in marked contrast to that of the dark brecciated shales, which overlie the gravels, and contain a few little streaks of ore. The gravel is such as might be expected to accumulate in a steep side gulch rather than in an important stream.

Above the Iron Giant, and belonging to the same group (M. M. P. group) is the old M. M. P. tunnel, now caved in and abandoned. It is said to have produced some ore from a "contact," and to have opened up some large masses of pyrite.

MISCELLANEOUS PROSPECTS.

GENERAL.

Under the heading of "Miscellaneous prospects" will be described a few workings which can scarcely be classed as productive mines, and yet which offer some points of interest in a general treatment of the region. In addition to these, however, there still remain numerous prospects and abandoned workings, detailed accounts of which would possess no general value, and are, therefore, omitted.

ATLANTIC CABLE MINE.

This is an old prospect situated on the northern edge of Rico, in Devonian limestone. With it may naturally be described the Smuggler, Shamrock, and Riverside claims, on the west side of the river. As the ore on these claims outcropped plainly in the banks of the Dolores River and of Silver Creek, they were among the earliest in the district to be exploited. But the ore proved of such low grade and so irregular in its occurrence that work was abandoned, after unsuccessful attempts to concentrate the ore for galena. In 1900 the Atlantic Cable claim was being prospected by shallow shafts, with a view to the extraction of zinc ore.

The ore consists chiefly of sphalerite, chalcopyrite, pyrite, and a little galena, in a dark-green, compact gangue consisting largely of chlorite. With the chlorite, however, is usually associated more or less cryptocrystalline cherty material, in knots or bunches, nests of wollastonite and garnet, and veinlets of epidote. Near the Dolores River, and particularly on the Smuggler and Shamrock claims, the ore changes to masses of specularite and chlorite. The limestone, which constitutes the country rock of the ore, has a curious, blotchy appearance, briefly referred to by Cross and Spencer[1] as due to metamorphism. When a surface of this limestone is examined, patches of white crystalline limestone and areas of chert and of dark-green chlorite are seen to be so disposed as to strongly suggest a breccia structure, the original sharpness of which has been somewhat obscured by later metamorphism. It is believed that the hypothesis thus suggested best explains this peculiar spotted appearance. The limestone, originally impure, and situated in the heart of the Rico uplift, was brecciated, the brecciation apparently involving some layers of shale which are exposed in less disturbed condition in the bottom of what is known as the Gas shaft, on the Job Cooper claim, which adjoins the Atlantic Cable on the east. After brecciation, the limestone was metamorphosed, possibly as Cross and Spencer[2] suggest, by the intrusion of the monzonite between Aztec Gulch and Iron Draw. As a result of this metamorphism, the fragments of limestone recrystallized as pure white marble, in some cases separated from cherty fragments by reaction rims of epidote, garnet, and wollastonite, the shale was chloritized, and more or less garnet, wollastonite, chlorite, and epidote were developed in bunches and streaks throughout the mass. It is impossible to distinguish here between this metamorphism and the ore-deposition. The two processes went on together, as shown by the close association of the sphalerite, specularite, chalcopyrite, galena, and pyrite, with the chlorite, and the frequent bunchy or knot-like occurrence of these ores.

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[1] Loc. cit., p. 45.

[2] Loc. cit., p. 46.

Although some of the ore masses have a thickness of 25 feet, and contain excellent zinc ore (up to 30 per cent of zinc), their erratic occurrence has so far baffled attempts at systematic exploitation. They sometimes extend irregularly into the white limestone, dying out in small stringers and bunches. In other directions they grade into masses of specularite and chlorite or stop abruptly at some fracture plane containing a slight seam of gouge. No particular regularity of trend is noticeable in these fractures, nor is it certain that they are to any extent fault fissures. They appear rather to be fractures that originally partly controlled the deposition of the ore.

IRON DOLLAR AND EIGHTY-EIGHT MINES.

The Iron Dollar shaft is sunk in the bed of Silver Creek, about half a mile from the mouth of this stream. The workings are abandoned and full of water. The dump shows quantities of pyrite, specularite, and quartz, with some chalcopyrite. Chlorite, epidote, and calcite are also abundant, indicating that the deposit is mineralogically similar to that of the Atlantic Cable. The Eighty-Eight shaft, about 150 feet north of the Iron Dollar, shows a dump of similar character.

About 150 feet west of the Iron Dollar shaft a tunnel about 225 feet in length has been run into the hill in a direction N. 30° E. This tunnel cuts a lode, which is probably the one formerly worked in the now inaccessible Eighty-Eight shaft. The lode strikes N. 85° W. and dips N. at 85°. It is rather irregular and in places consists of several stringers of nearly barren quartz in Lower Hermosa shales. The latter, for a distance of 4 or 5 feet on each side of the lode, are much altered, and locally transformed to a mass of specularite, pyrite, chlorite, and other minerals, in the mineralogical association so characteristic of the Atlantic Cable group of claims. In this case, however, the metamorphism occurs in Lower Hermosa shales, the underlying Ouray limestone being not exposed, and it is plainly connected with lode fissures. This connection, and the general east-west trend of the lode, suggests that the latter or some generally parallel fissures may have been instrumental in effecting the ore deposition of the Atlantic Cable. The occurrence is particularly interesting in showing that the specularite and chlorite may form by metasomatic replacement of the shales alongside of a lode fissure.

BURNS MINES.

These are prospects situated on both sides of the river at Burns station, in Lower Hermosa beds. The A. B. G., on the west side of the stream, is developed by tunnels run in on a large northwesterly lode, showing an average width of about 4 feet. The strike of the lode varies from N. 20° W. to N. 45° W. It dips northeast at about 85°. The fissure is occupied by a rather irregular vein containing galena, sphalerite, and pyrite in a gangue of quartz and calcite, and accompanied by much soft gouge on both walls. The ore is low in grade and has not yet been profitably worked.

On the southwest side of the lode, and probably connecting with it, is a blanket deposit, with a northerly dip of 10°. This consists of a layer of partly oxidized, crumbling pyrite, about a foot in thickness, underlain by limestone and overlain by calcareous shale. The ore is separated from the overlying shale by a gouge, and the shales themselves are partly decomposed to clay. In the northwest part of the blanket workings a bed of limestone appears between the ore and overlying shale and attains a maximum thickness of 2 feet. On the southeast this limestone thins, softens, and passes into gouge.

Some ore has been mined from this blanket, and is said to carry from 35 to 40 ounces of silver and $4 in gold per ton, and from 4 to 6 per cent of copper.

On the east side of the river is the C. V. G., a prospect which is probably on the Pigeon lode. The workings had caved near the tunnel mouth in 1900 and were inaccessible. The lode is said to be 40 feet wide and to contain quartz and pyrite.

GEOLOGY AND ORE DEPOSITS OF THE ELKHORN MINING DISTRICT, JEFFERSON COUNTY, MONTANA

BY

WALTER HARVEY WEED

WITH

AN APPENDIX ON THE MICROSCOPICAL PETROGRAPHY OF THE DISTRICT

BY

JOSEPH BARRELL

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GEOLOGY AND ORE DEPOSITS OF THE ELKHORN MINING DISTRICT, JEFFERSON COUNTY, MONTANA.

By WALTER HARVEY WEED.

CHAPTER I.

INTRODUCTION.

FIELD WORK AND ACKNOWLEDGMENTS.

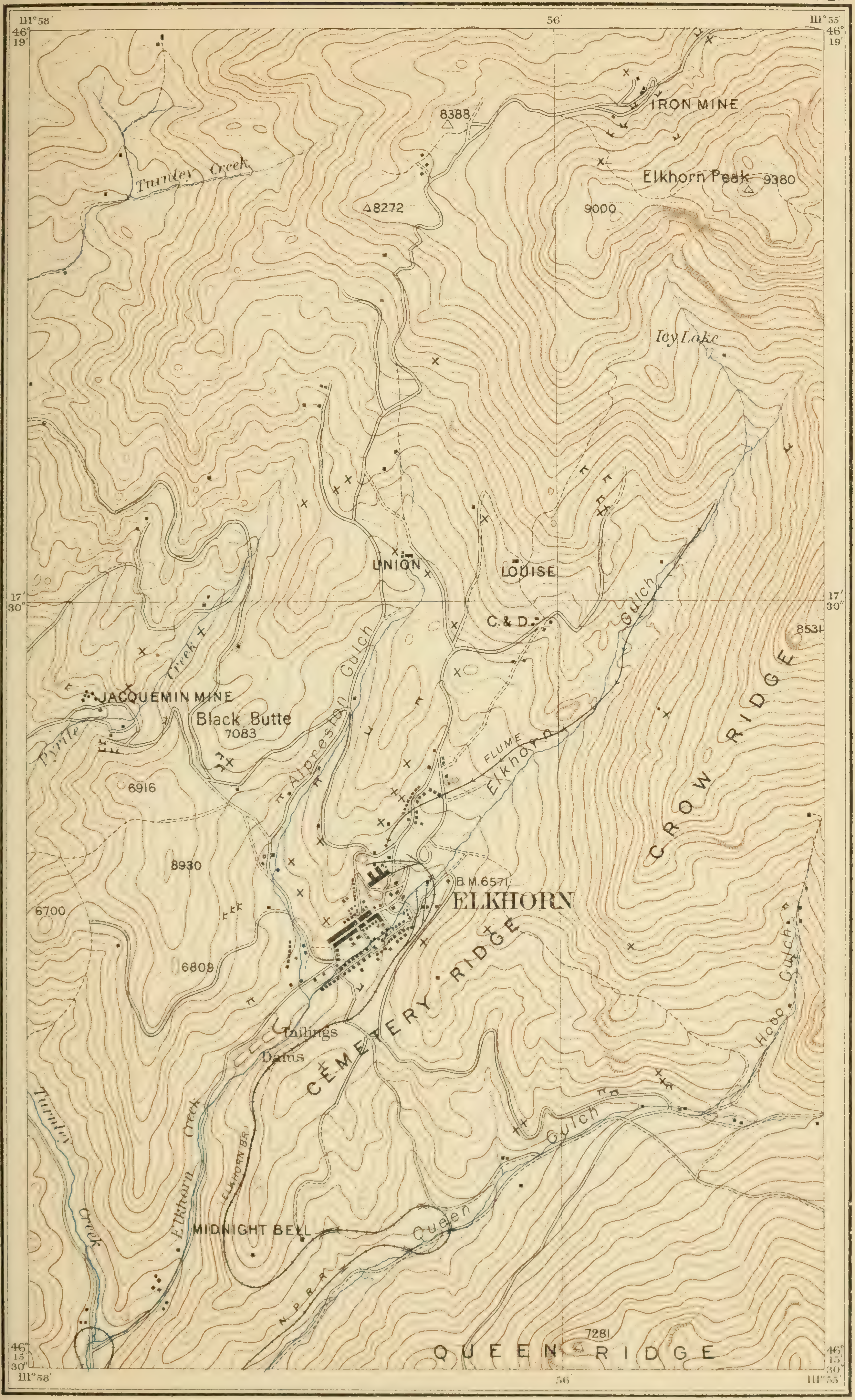
The Elkhorn district was first visited by the writer in the summer of 1896, while studying the general relations of the granite area in which the Butte ore deposits occur. Mr. Walter S. Kelley, superintendent of the Elkhorn mine, called attention to the value of an investigation of this property, whose extensive development and interesting geological occurrences make it in some respects unique among the ore deposits of Montana. It was found that the ore deposit occurs on the borders of a great area of granite, and that in the immediate vicinity of the deposit there has been successive intrusions of igneous rock, breaking up through folded sedimentary and earlier igneous rocks. The district thus offered peculiarly favorable opportunities for a study of the relations of the igneous rocks to one another and of the effect produced by such intrusions upon adjacent sedimentary rocks. In 1897 a second visit was made to the district, and a fortnight was spent in a reconnaissance of the entire area and a determination of the more salient features of its geology. The observations made at this time confirmed opinions previously formed, and detailed mapping and study of the district were determined upon. In the summer of 1899 Mr. R. H. Chapman was detailed to make a topographic map covering the more interesting geological features of the region immediately about Elkhorn. The writer planned to do the detailed geological mapping himself, but the necessity of further study of the Butte copper deposits prevented his spending the summer upon this work. Therefore he took to the district Dr. Joseph Barrell, who was acting as field assistant for the season, and went over the ground with him, indicating the distinctions to be made and the problems to be worked out. The areal distribution of the rocks was mapped by Dr. Barrell during the months of August and September, and great credit is due to him for the care with which the obscure boundaries of the different rocks have been traced out. At the same time he made careful studies of the relations of rock masses, of the changes in the igneous rocks resulting from contact metamorphism, and of possible assimilation of material by the intruding magma. The detailed facts upon which many of the inductions made in this report rest were, therefore, gathered by Dr. Barrell. The underground work was done by the author. The petrographic study of the rocks was made by Dr. Barrell, under the direct supervision of Prof. L. V. Pirsson, in the petrographic laboratory of the Sheffield Scientific School of Yale University. The geological notes obtained by Dr. Barrell, together with this report upon the petrography of the rocks, formed the basis of a thesis prepared by him in partial fulfillment of the requirements for the degree of doctor of philosophy. The paper thus prepared has been largely drawn upon by the writer in preference to the original field notes, while the petrographic report is the same as that of the thesis, save only that much of the purely speculative portion has been omitted.

The topographic map of the district (Pl. XLII) includes an area of 1½ by 2½ miles, on a scale of 1:32500, or about 2 inches to a mile, the relief being shown by 50-foot contours. Where the Elkhorn district is mentioned in these pages this area is meant. All the more important prospect pits are located and the more important geological features are included within the area selected.

The chemical analyses in this report have been made in the laboratory of the Geological Survey by Dr. H. N. Stokes.

Thanks are especially due to Mr. Walter S. Kelley, former manager of the Elkhorn mine, for his hospitality and for kindnesses too numerous to mention. The author is indebted to him for the use of the mine maps and for valuable specimens of minerals and ores, also for the use of a room kindly placed at his disposal, as well as for many personal hospitalities. Thanks are also due to Mr. William Davey, former foreman of the mine, and to Mr. Thom Tyack, assistant foreman, for many courtesies.

This report will be regarded by some as an account of an exhausted and worked-out district, as the Elkhorn mine, the chief producer, after a productive period of about twenty years, was closed down and abandoned. In 1901, however, it was reopened, and promises to be again a producer. The other properties are as yet in the prospect stage, and, though promising, did not offer sufficient exposures and data for a complete report. It has seemed advisable, however, to present somewhat fully the facts concerning the Elkhorn mine, as they will be of interest in connection with the future development of other properties in the country. The depth to which the mine was worked and the lateral extent of the development offered peculiarly favorable



TOPOGRAPHIC MAP OF THE ELKHORN DISTRICT

Topography by R. H. Chapman
1899

Scale
0 ½ 1 MILE

Contour interval 50 feet

JULIUS BIEN & CO. N.Y.

conditions for study, and no apology is needed for presenting an account of a mine which has yielded such large amounts of the precious metals and which must ever be regarded as one of the big mines of Montana.

GEOGRAPHIC POSITION.

The Elkhorn district is situated in the center of Jefferson County, in the central portion of the mountain region forming the western part of the State of Montana. The town of Elkhorn, which is in the center of the district, lies about 18 miles east of Townsend, a town on the Missouri River and on the main line of the Northern Pacific Railway. It is 20 miles southeast of Helena and about the same distance northeast of Butte. It is accessible by a branch line of the Northern Pacific Railway, and is about 12 miles east of the town of Boulder, which is on the Montana Central division of the Great Northern Railway. The accompanying map (fig. 72) shows the situation of the district with respect to the main drainage lines and mountain ranges of the State. Crow and Elkhorn peaks rise to an elevation of 9,500 feet only a short distance to the north and northeast of the town, being the highest peaks for many miles around. These two peaks are the culminating summits of a group of mountains lying west of the Missouri River Valley and isolated from the neighboring ranges of the Rocky Mountains by broad, open valleys on the north, east, south, and west. This group, to which the name Crow Creek Mountains or Crow Mountains is often applied, has a crest line in shape somewhat resembling a horseshoe, with the opening facing eastward and trenched by Crow

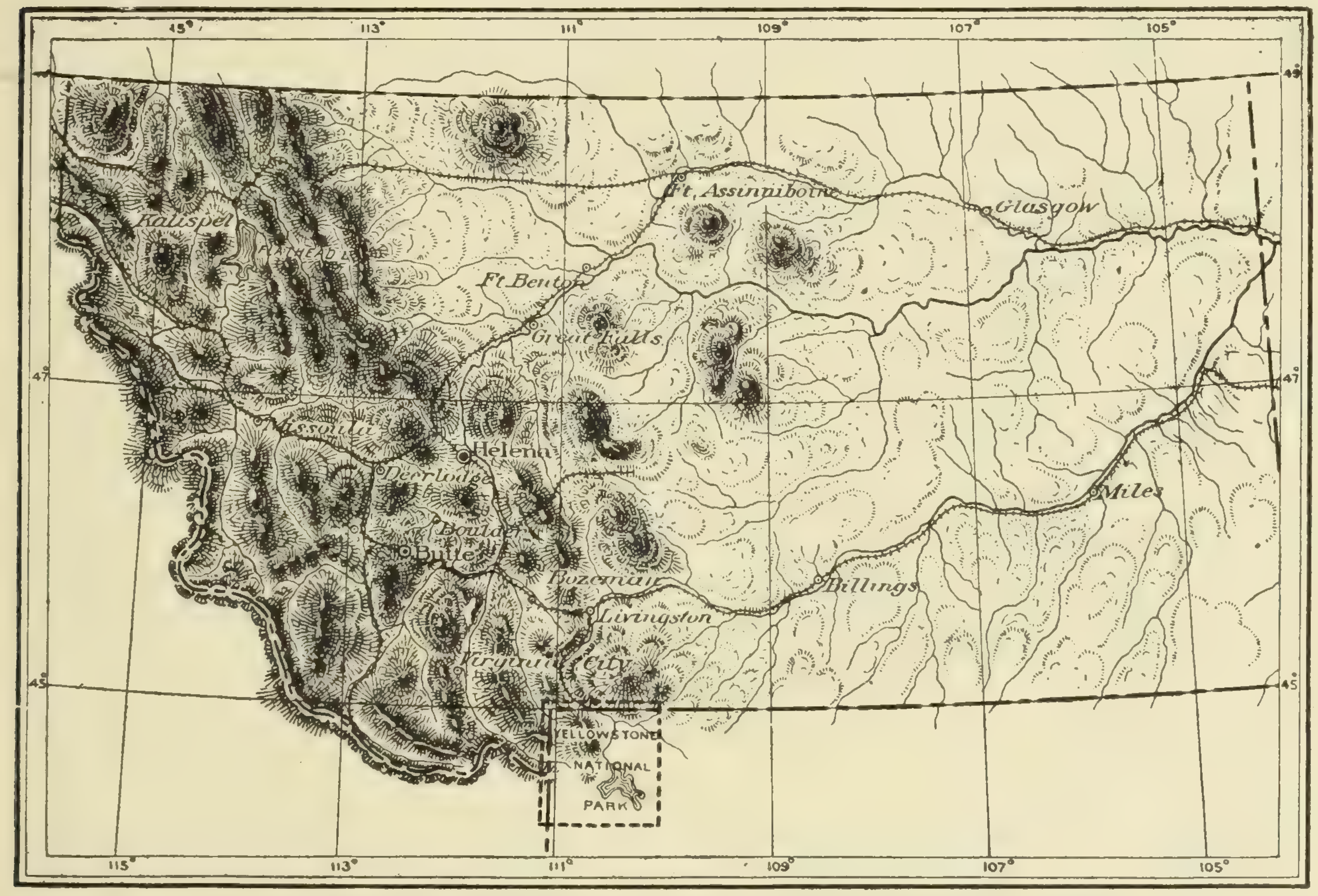


FIG. 72.—Index map of Montana, showing location of Elkhorn district.

Creek, a tributary of the Missouri. This mountain district, which owes its elevation primarily to the folding of sedimentary rocks, but chiefly to the durability of the finer-grained igneous rocks which cap its summits, is drained by streams which are generally radial to its flanks. On the west, however, a long north-south fault, marked by the drainage way of Prickly Pear Creek and Boulder Valley, separates it from the complex of mountain peaks and ridges known as the Boulder Mountains. It is thus seen that the Crow Mountains not only lie well within the mountain region of the State, but are a unit both topographically and geologically, and not merely a part of some larger district.

TOPOGRAPHY.

The district is one of great relief, as is well shown on the topographic map, Pl. XLII. In general the slopes, though steep, are not precipitous. While the rocks are usually well exposed, there is considerable soil and vegetation. Owing to the elevation of the region, it receives abundant precipitation in the form of rain and snow and is often the scene of midsummer snowstorms even when the adjacent lowlands are bathed in sunshine. As might therefore be imagined, the climate is somewhat rigorous and the winters are long. For this reason there is an abundant drainage, which is all concentrated in the stream known as Elkhorn Creek, while immediately outside of the area mapped Crow Creek and Prickly Pear Creek also take their heads. The district, though small, shows the usual peculiarities of drainage noticed where igneous rocks and limestones are found close together. In the former rocks the streams are perennial, while in the latter the drainage ways carry running water only in times of heavy rain or melting snows. There is a concordant association of plant life, the limestones being in general bare and arid and the igneous areas usually well wooded and covered with an abundant herbage, but this is dependent on rainfall, which is a function of altitude, so that the general statements given above are true only where the elevations are similar. In the lower part of Elkhorn Creek, where it enters the broad, open valley of Boulder River, the areas of both igneous and limestone rocks are arid and devoid of all arboreal vegetation.

Elkhorn is one of the most picturesquely situated mining towns of the State. It lies near the head of a mountain valley at a point where a sudden broadening occurs. To the south the gulch is narrow and canyon like, while above it changes from a moraine-dammed gorge to a high mountain amphitheater. Nestling close up under Elkhorn and Crow peaks, at an elevation of 6,500 feet above the sea, it receives tribute from many cloud banks which, drifting across the lower mountain country to the west, are caught by Elkhorn Peak. The scenery is not typically alpine, though rugged and picturesque. The view from the town is, however, a broad one, including a wide stretch of valley and a mountain range to the south.

The town is built upon a steeply sloping bowlder apron, the front of a moraine that incloses the upper valley of the creek. The slopes near by are parked and wooded, and are in strong contrast to the arid and glaring limestone hills seen in the valley to the south. The most striking feature of the scenery is Elkhorn Peak, whose summit rises 3,000 feet above the town and is about 1½ miles distant from it. The mineral wealth of the district is found in the altered limestones near their contact with gabbro-diorite intrusions and where broken through by offshoots from the mass.

HISTORY.

The Elkhorn district was prospected early in the history of the State and numerous quartz locations were made in the years preceding 1870, but the district did not attract attention until the A. M. Holter lode became a producing mine. This property, later known as the Elkhorn mine, has been the principal and, in fact, almost the only producer of the district, and was for many years one of the prominent silver mines of the country. The history of the mining industry of this district is therefore the history of this mine. The Elkhorn property was sold by its original locators to A. M. Holter, after whom the claim has been named. Mr. Holter organized the Elkhorn Mining Company, and the mine has since been known as the Elkhorn mine. A 5-stamp wet crushing free-milling plant was erected by the first owners, and as the surface ores were free milling and yielded readily to simple amalgamation, satisfactory results were realized in the early history of the property. With increased depth, however, the oxidized ores became refractory and the loss in treatment became as high as 50 per cent of the silver values. In 1881 the mine was developed to a depth of 300 feet, and the nature of the ore made it evident that a new mill would have to be erected and chloridization adopted. Owing to a disagreement among the owners and the necessity of enlisting new capital, the property was idle for the greater part of the year 1882, though it yielded 4,285 ounces of fine silver during that year. In 1883 the property passed into the possession of the Elkhorn Mining Company, a new hoist was erected, and a 10-stamp chloridizing mill was put up, with a capacity of about 11 tons a day. The ore was stamped fine, roasted, and amalgamated in combination pans without grinding. The result was a saving of 90 per cent of the values and a bullion product aggregating $188,375 in silver and $2,320 in gold for the first ten months after installment. The bullion product was 900 fine in silver, with a little gold, the principal impurity being copper.[1]

The old Elkhorn Company subsequently increased its battery to 20 and then to 25 stamps and worked the mine down to the 800-foot level, where lean ore was encountered, and some doubt was expressed as to whether the property was not worked out. In 1888 the Montana corporation sold out to a new company organized in London, which took the name and property of the old corporation, remodeled the mill, and instituted a policy of vigorous development, under which the mine has yielded 6,500,000 ounces of silver and 5,000 ounces of gold since 1888. The total production of the mine has been computed by Mr. Walter S. Kelley, the manager of the property, from the company's books. The figures are given in round numbers only, and those for the earlier period are only approximate.

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[1] Report of the Director of the Mint for 1884, p. 302.

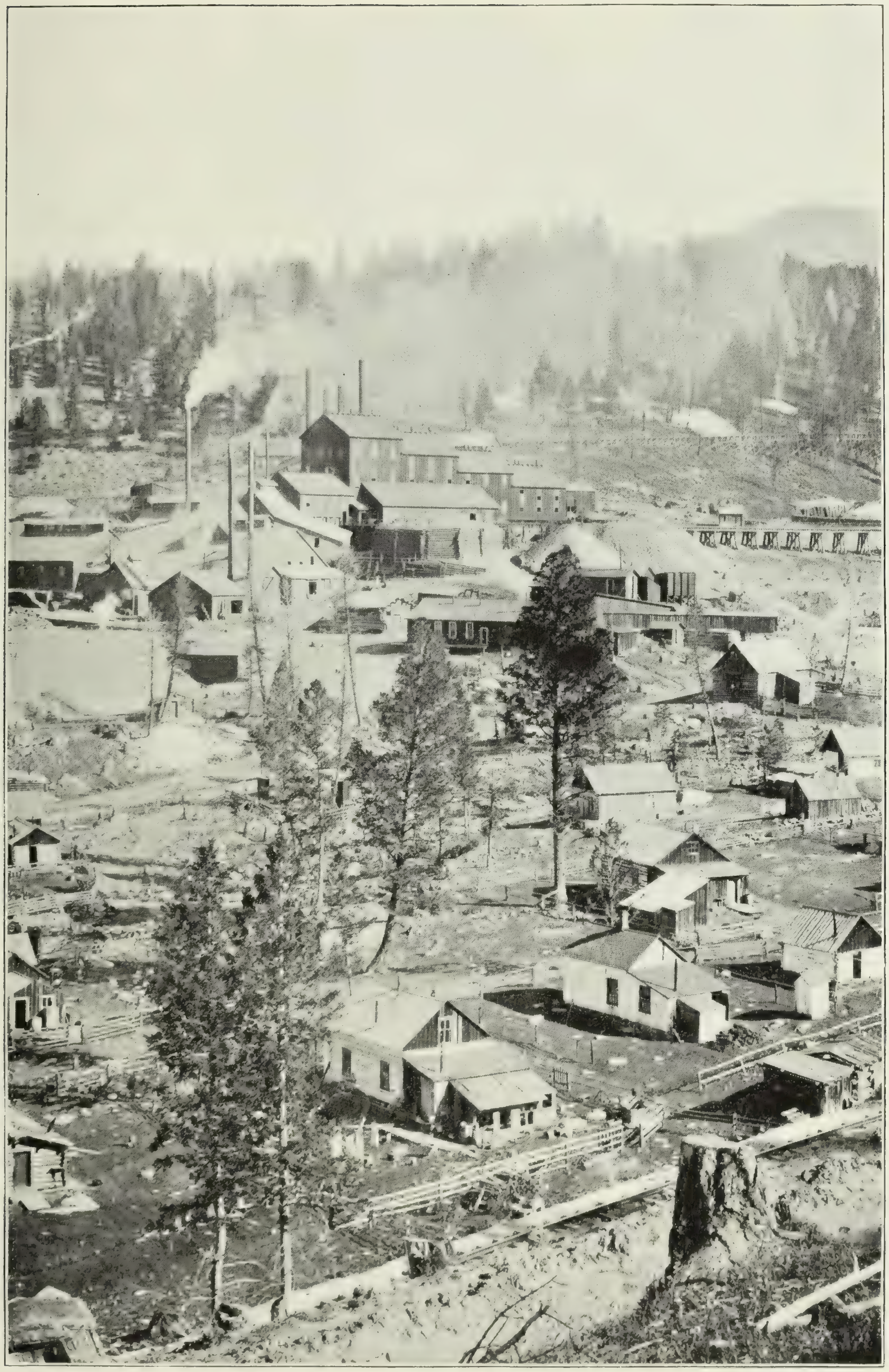
From 1884 to January, 1900, the mine was in continuous operation, save for a short time in 1886, when an accident to the pumps resulted in the flooding of the mine up to the 500-foot level for several months.

In 1896 the ore in sight was nearly exhausted, and preparations were made to abandon the mine, but Mr. Walter S. Kelley, who at that time became general manager of the property, by careful exploration work disclosed new ore bodies, and continued to work the property until December, 1899. In the autumn of 1899 it became apparent that the expense of pumping, which necessitated heavy fuel bills, combined with the small extent and low grade of the ore in sight, would not warrant the further operation of the mine. The cost of the ore extracted had steadily risen during the last few years until in 1898 it reached a total of $15.60 per ton, while the expense of milling increased to $9.50 per ton. It was therefore decided to close down and abandon the property.

The development of the Elkhorn has played an important part in the settlement and betterment of the State. The monthly pay roll aggregated over $15,000, as besides the men employed at the mine and mill a large number of wood choppers were regularly at work. The town of Elkhorn, a settlement with a population of about 600, was built and maintained practically by this one mine, and the supplies shipped to the district for mine and town kept the railroad line busy for many years. The passing into history of this great property is felt not only at the town of Elkhorn, but in the ranches, for whose produce it furnished a market, and in the parts of the State from which it drew supplies.

The former inaccessibility of the district, situated as it was in the heart of the mountains and until recent years remote from railroad communication, deterred active prospecting for a long time; moreover, in the early years of the Elkhorn mine, supplies, particularly salt, were very expensive, so that the cost of treatment was heavy.

In 1886 the Northern Pacific Railway built a branch line to Wickes to get the ore-carrying business of the Alta and Comet mines. About two years later the marvelous development of the Butte copper deposits induced this company to begin an extension of this branch



ELKHORN MINE AND MILL.

southward to that city. At the same time the Montana Central, now a part of the Great Northern system, was under construction, and a railway-building contest began, with Butte as the objective point. The Montana Central secured the more favorable right of way, and the Northern Pacific line, after being built to Bernice, was not completed. Both roads pass through Boulder, the county seat, 12 miles west of Elkhorn, so that a year later the Northern Pacific Company was induced to build a branch line through the Boulder Valley and up the gorge of Elkhorn Creek. The building of this road was a difficult piece of engineering, as the grade to be overcome was excessive, but by the use of short loops a road was constructed on which short trains could be hauled. A triweekly train service was established, making it possible to ship the silver-lead ores which were discovered in great abundance in the deep workings of the Elkhorn mine, and which were also found to a limited extent in other properties in the district.

PRODUCTION.

The successful development of the Elkhorn mine resulted in very energetic prospecting of the adjacent claims during the first few years of its existence. The report of the Director of the Mint for 1884 mentions 12 mines, all close to the Elkhorn, which were said to show well-defined ore bodies, carrying good values in silver and sometimes in gold and copper, and which were at that time developed by prospect shafts over 20 feet deep. Of those noted in that report, the Keene, Union, and C. and D. have been developed into mines from which ore has been shipped at various times, but the properties have thus far proved disappointing to the owners, and their yield has been insignificant compared with that of the Elkhorn mine. The C. and D. is the only one from which any returns of production are available. A small smelter was built in 1886 and run for a short time upon the ores from this mine. The product for 1886 is given in the report quoted as $4,068 worth of bullion. For 1887 the same authority gives the product of the C. and D. mine as $10,335 in gold and $10,320 in silver, and for 1888 as $2,661 in gold and $10,433 in silver.

In later years the C. and D. has been leased at various times, and the ore extracted has been shipped to custom smelters. The ore, however, has been too low grade to work profitably, and it is only when pockets of galena have been found that any profit has been made in the workings of the property. The other properties of the district have been worked at various times in the last twenty years, but only for short periods, and have not been developed into producing mines. An exception should be made of the Elkhorn Queen, which lies over the ridge beyond Queen Gulch, just outside the limits of the area mapped.

The following tables give the yearly production of the Elkhorn mine:

Yearly production of Elkhorn mine from 1882–1889.

Years.	Silver.	Gold.
	Dollars.	*Dollars.*
1882	[a]4, 285	....
1883	([b])	....
1884	168, 375	2, 320
1885	218, 828	1, 338
1886	276, 051	....
1887	([b])	....
1888	476, 754	6, 068
1889	[a]389, 353	4, 450

[a] Ounces.

[b] Not reported.

Yearly production of Elkhorn mine from 1890–1900.

Years.	Silver.		Gold.		Lead, smelting ore.
	Mill bullion.	Smelting ore.	Mill bullion.	Smelting ore.	
	Ounces.	*Ounces.*	*Ounces.*	*Ounces.*	*Pounds.*
1890	418, 516. 02	102, 628. 81	202. 104	168. 557	187, 214
1891	345, 079. 62	271, 914. 98	406. 287	485. 854	619, 054
1892	486, 033. 01	422, 270. 17	537. 721	519. 917	794, 305
1893	428, 613. 07	332, 195. 98	360. 137	349. 629	548, 382
1894	470, 706. 99	281, 998. 43	353. 598	259. 809	448, 311
1895	474, 390. 68	77, 398. 77	359. 304	79. 435	136, 554
1896	486, 720. 95	90, 787. 29	339. 975	85. 566	149, 367
1897	489, 959. 78	96, 872. 10	420. 244	109. 147	179, 341
1898	375, 963. 04	214, 908. 89	243. 605	230. 626	532, 429
1899	364, 906. 08	[a]193, 374. 55	258. 413	140. 380	357, 827
1900	20, 362. 18	....	13. 486	....	....
Total	4, 361, 251. 42	2, 084, 349. 97	3, 494. 874	2, 428. 920	3, 952, 784

[a] Ore shipments.

In addition to the above there was an average of about 7,500 pounds of copper contained in the mill bullion each year.

Production of Elkhorn mine by periods.

Years (inclusive).	Silver.	Gold.
	Ounces.	*Ounces.*
1875–1884	500,000	500
1885–1889	2,000,000	2,000
1890–1899	6,402,000	6,000
Total	*a* 8,902,000	8,500

a And 4,000,000 pounds of lead.

From what has been stated, it will be seen that the economic geology of the district is almost entirely an account of the Elkhorn mine, and, indeed, not only are the workings of the other properties small, but they were at the time of visit inaccessible. A large number of mining claims have been located and prospecting pits sunk over nearly every part of the district. Thus far, however, the only ore deposits worthy of serious attention appear to be in the areas of altered sedimentary rocks. Small veins have been found near the summit of Elkhorn Peak and in the amphitheater below it, but up to the present time no ore bodies large enough to warrant extensive development work have been discovered. The Jacquemin mines, situated about 2 miles west of Elkhorn, on a branch of Turnley Creek, have shipped considerable ferruginous ore, which was too low grade to work on account of its precious-metal content alone, but which was needed at the smelter as a flux. The iron mines on the north side of Elkhorn Peak are also worthy of attention, as they expose large bodies of rather pure iron ore. As a district, the future can not be said to be bright, as the low-grade character of the ores precludes their treatment at present prices. The gold ore of the Dolcoath is, however, a possible exception.

MILLING.

The Elkhorn ores are of two classes—smelting and milling. The smelting ores consist chiefly of argentiferous galena and are shipped to the smelter. The milling ores are a mixture of silver sulphides and gray copper, and are treated by the ordinary chloridizing process. A careful separation of the ore is, of course, made in the mine, and this, fortunately, is made the more readily because the milling ore is almost wholly quartzose and comes from the hanging-wall bodies. The milling ore is treated at the mine in an ordinary pan amalgamation mill.

In milling the ores the treatment has varied somewhat in recent years, owing to their increasingly refractory character. In general, the process consists in a dry stamping of the siliceous ore, salt being added to the ore as it is fed to the stamps, whence the dry pulp is conveyed directly to the Brückner roasters. The large amount of gray copper and galena in the ore treated in the last few years has made it necessary to use as much as 15 per cent of salt. In the free ores from the upper levels of the mine 5 per cent was sufficient. The roasted ore is taken in cars to the cooling floor, where it is left in heaps for ten to fifteen minutes, then holed by inserting a bar vertically and then horizontally, making a free air passage through the center of the heap. The heap is subsequently leveled down to a thickness of 1 to 2 feet and then trenched by ditches. The cooled ore is then conveyed in wheelbarrows to the pan room, where it is mixed with salt and sulphuric acid and put in amalgamating pans, lime being added to clear the quicksilver. After grinding in the pans the pulp is drawn into settling pans, which, when half full of pulp, are filled up with water and stirred slowly for half an hour. The top peg is then pulled out and a stream of water run in.

The cost of treatment has steadily increased as the ores became more refractory. This is largely due to the increasing amount of salt used. Thus in 1896 the cost of salt per ton of ore milled was $1.88, rising to $2.14 in 1897, and to $2.22 in 1898. Fuel cost but $1.05 in 1896, rose to $1.10 in 1897, and to $1.40 in 1898. These two items account for the increase from $7.17 in 1896 to $9.49 in 1898.

The careful returns made by the mine manager, Mr. Walter S. Kelley, to the company, show in great detail the cost of treatment per ton of ore milled. In considering the following table, which is copied from the manager's report for the calendar year 1896, it should be remembered that the ore was extremely base. The table shows the amount of ore treated, of bullion produced, etc.

Work performed by Elkhorn mill in 1896.

Batteries (20-stamp) in service	315 days, 9 hours.
Pans in service	357 days, 15 hours.
Ore crushed	13,762 dry tons.
Salt used	2,249 tons.
Average amount crushed per stamp per day	1.745 tons.
Average assay value of pulp	38.435 ounces silver per ton.
Pulp panned	13,718 dry tons.
Average assay value of tailings	3.435 ounces.
Portion saved according to assay	92.775 per cent.
Portion saved according to bullion returns	92.313 per cent.
Silver produced	486,721 fine ounces.
Gold produced	339.975 fine ounces.

The details of cost are given as follows:

Analysis of cost of milling per ton of pulp treated in 1896.

Labor account.		Supplies account.	
Superintendence and foreman	$0.3734	Chemicals	$0.0772
Engineers	.2134	Lubricants	.0364
Crusher man	.1571	Illuminants	.0032
Dryer man	.1578	Fittings	.0124
Battery man	.2147	Tools	.0045
Roaster man	.1847	Castings	.2308
Cooling floorman	.1569	Iron and steel	.0186
Carmen	.3166	Lumber	.0143
Amalgamators	.2131	Charcoal	.0387
Pan helpers	.1568	Belting	.0245
Assayer	.0722	Quicksilver	.3486
Storekeeper	.0437	Salt	1.8800
Millwright	.0512	Fuel	1.0572
Machinists	.1916	Assay office	.0374
Teams and labor	.1453	Stables	.0240
Watchmen	.0803	Office and incidentals	.0763
Tailings dam	.0828	Freight	.0152
Office expenses	.0656	Insurance	.0940
		Machine shop	.0039
		Legal expenses and taxes	.2463
		Sundries	.0538
Total	2.8772	Total	4.2973

Cost of labor per ton	$2.8772
Cost of supplies per ton	4.2973
Total	7.1745

Analysis of cost of milling per ton of ore treated from 1896–1898 inclusive.

	1896.	1897.	1898.
Superintendence, including office expenses	$0.37	$0.4298	$0.5217
Labor	2.4382	2.6475	3.3058
Salt	1.88	2.2187	2.1406
Fuel	1.0572	1.1171	1.3973
Quicksilver	.3486	.4479	.8904
Chemicals	.0772	.0623	.0661
General repairs and supplies	....	.6323	.7214
Surface expenditures	....	.1567	.2034
Taxes, insurance, and legal expenses	.2463	.2599	.2423
Total	7.174	7.9722	9.4890

The fuel cost is increased also, owing to increased depth of the mine, the larger amount of water due to new water courses cut in prospecting upper levels, and the increased use of compressed air.

Analysis of cost of mining per ton of ore hoisted from 1896–1898, inclusive.

[Based upon total expenditure in mine.]

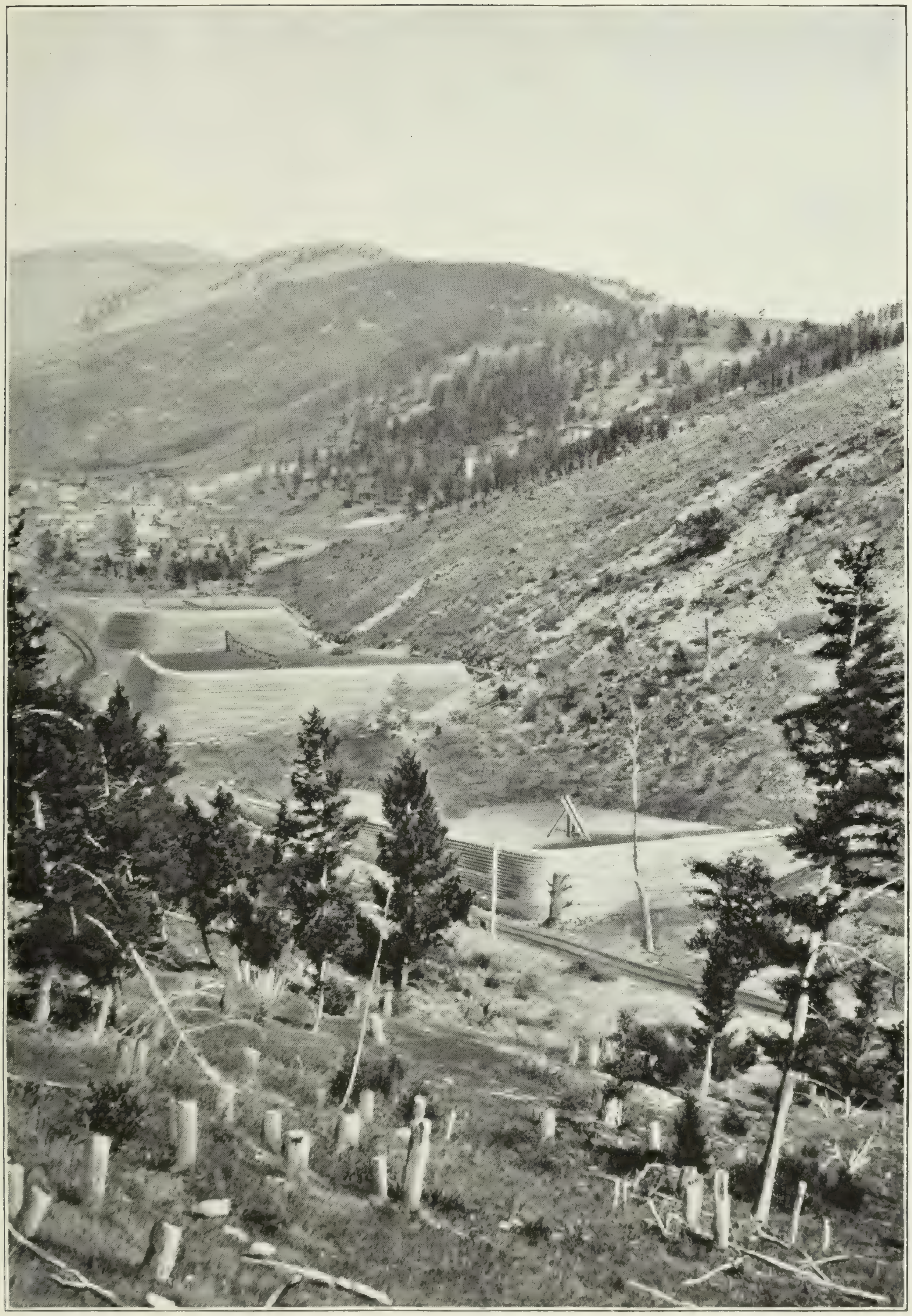
	1896.	1897.	1898.
Superintendence, including office expense		$0.7163	$0.7833
Mine labor		9.1486	9.0269
Ore-house labor		.6212	.7246
Fuel		3.0343	3.0993
Explosives		.6404	.8090
Timber		.0992	.1250
Illuminants		.0788	.0768
General repairs and supplies		.4525	.5362
Surface expenditures		.1495	.1892
Taxes, insurance, and legal expenses		.2732	.2238
Total	$12.384	15.2140	15.5941

The cost of mining was, in 1896 and subsequent years, very greatly increased over that of former years by reason of the exhaustion of the large ore bodies formerly worked; the cost was largely increased, also, by reason of the ore coming from many small stopes and faces.

Amount, contents, and value of ore sold.

Year.	Ore.	Silver.	Gold.	Lead.	Total value.	Value per ton.
	Tons.	*Ounces.*	*Ounces.*	*Pounds.*		
1898	1,700.309	214,908.89	230.626	532,429	$104,945.83	....
1897	715.241	96,872.10	109.147	179,341	48,478.44	$67.78
1896	554.234	90,787.29	85.566	149,367	50,355.59	90.85

A peculiar feature of the reduction plant at Elkhorn is shown in Pl. XLIV. The tailings are impounded by a series of dams built up of sacks filled with tailings sand. The bags are those in which the salt used by the mill is received. Their cost is therefore trifling, and when filled with sand they form excellent retaining walls. These dams are made necessary by the fact that the water is used by the ranchmen downstream for irrigation.



TAILINGS DAMS OF ELKHORN MINE IN GORGE OF ELKHORN CREEK, BELOW THE TOWN.

Shows narrowing of the valley where creek leaves altered limestones and cuts through the quartz-diorite-porphyry. Tailings dams are opposite slide of porphyry débris. Main wagon road is seen in bottom of gulch. Higher wooded area on mountain covers Carboniferous limestone. Smooth, rounded summit of Crow Peak seen in distance.

CHAPTER II.

GENERAL GEOLOGICAL FEATURES OF THE DISTRICT AND ITS RELATION TO THE SURROUNDING REGION.

The Elkhorn district comprises a small part of the southwest end of a group of mountains of very complex composition. For the benefit of the reader who may desire to know the relations of the district to the surrounding region a short résumé of the conditions, so far as they are known from the writer's studies, will be given in this chapter, together with a brief account of the leading features of the district itself. The district lies on the border of the great Boulder granite area, and includes a part of that area and also the borders of an area of folded limestones, shales, etc., which compose the long ridges lying east of Elkhorn and extending to the Missouri River. This area of folded rocks includes rocks of nearly all geological periods and of varied lithologic composition, all flexed in long arches and intervening troughs, forming the S-shaped folds, such as are found in the eastern ranges of the State. These folds can be traced westward and the individual formations readily followed to the Elkhorn district, where the normal lithologic character of the strata is lost as a result of contact metamorphism. The folding of the strata is clearly older than the extrusion of the igneous rocks which break up through them.

The Elkhorn mining district includes a wide variety of rock formations and, small as it is, within its borders is found evidence showing the nature of a long series of profound disturbances which have materially modified the geology of this part of the State. Lying on the western border of a great area of folded sedimentary rocks, the formations seen within its limits include a wide variety of lithologic types, now profoundly altered by later metamorphism, but in part at least traceable uninterruptedly into the normal unaltered formations a mile or two away. The sedimentary record of the earth's earlier history is, however, better studied in the region immediately east, since the Elkhorn region is peculiarly favorable for a study, not of sedimentation or the period of rock folding which succeeded, but of the many and varied events which occurred in a period of dynamic activity, initiated by volcanic outbreaks which, from evidence presented elsewhere in the State, are known to have commenced in early Tertiary time, and after the uplift of the region above the sea and the formation of mountain ranges by folding and synchronous erosion.

The evidence of the magnitude and power of the forces at work during what may fittingly be called the dynamic period of the history of the region is everywhere apparent, and the varied phenomena which resulted are exhibited here better than at any other place known to the writer. The detailed evidence gathered in the mapping of the areal geology confirms by abundant proof the deductions made during the reconnaissance of the district as to the relative age of the rocks and the metamorphic effects produced by the injection of great masses of molten rock.

The sedimentary rocks are devoid of all but the most fragmentary fossil remains, and are so generally metamorphosed that their original character is largely masked. Nevertheless, their sedimentary character is perfectly apparent, their bedding distinct, and the attitude of the beds easily made out. Moreover, while exact correlation of beds is not always possible, there is a general correspondence between the sequence observed here and that at localities near by, notably near Helena and near Whitehall, and the Carboniferous formations have been identified not only by fossils but by tracing the beds into the region of unaltered fossil-bearing strata a few miles southeast of the town.

The sedimentary rocks embrace a part of the Algonkian series known as the Belt terrane[1], and the Cambrian and other Paleozoic formations recognized in the Belt Range are undoubtedly represented here. The Jurassic has not been positively identified and the great series, several thousand feet thick, of altered argillaceous siliceous rocks, which directly overlies the Carboniferous must certainly be in part Cretaceous, for, although no paleontological evidence was obtained, the stratigraphic correlation is convincing. The Tertiary lake-bed deposits found in the larger intermontane valleys of western Montana do not occur in the district described, though found but a few miles to the south. The region probably formed a highland at the time the Tertiary lakes existed, from which the waste of subaerial erosion and probably also the lighter material poured out from volcanic vents were washed down into the Tertiary lake that filled the broad, open valley traversed by the Boulder River below Elkhorn Creek.

The igneous rocks are of several kinds, generally coarse grained, but of very widely differing appearance. The rocks are mostly of common types and present no difficulty in classification. They are of different age and represent successive events occurring in the Tertiary or post-Tertiary history of the region. The oldest rocks are gabbros and diorites, the youngest are aplitic granites. The former break irregularly up through sedimentary rocks and include fragments of them in their mass or resting upon their surface. Volcanic activity

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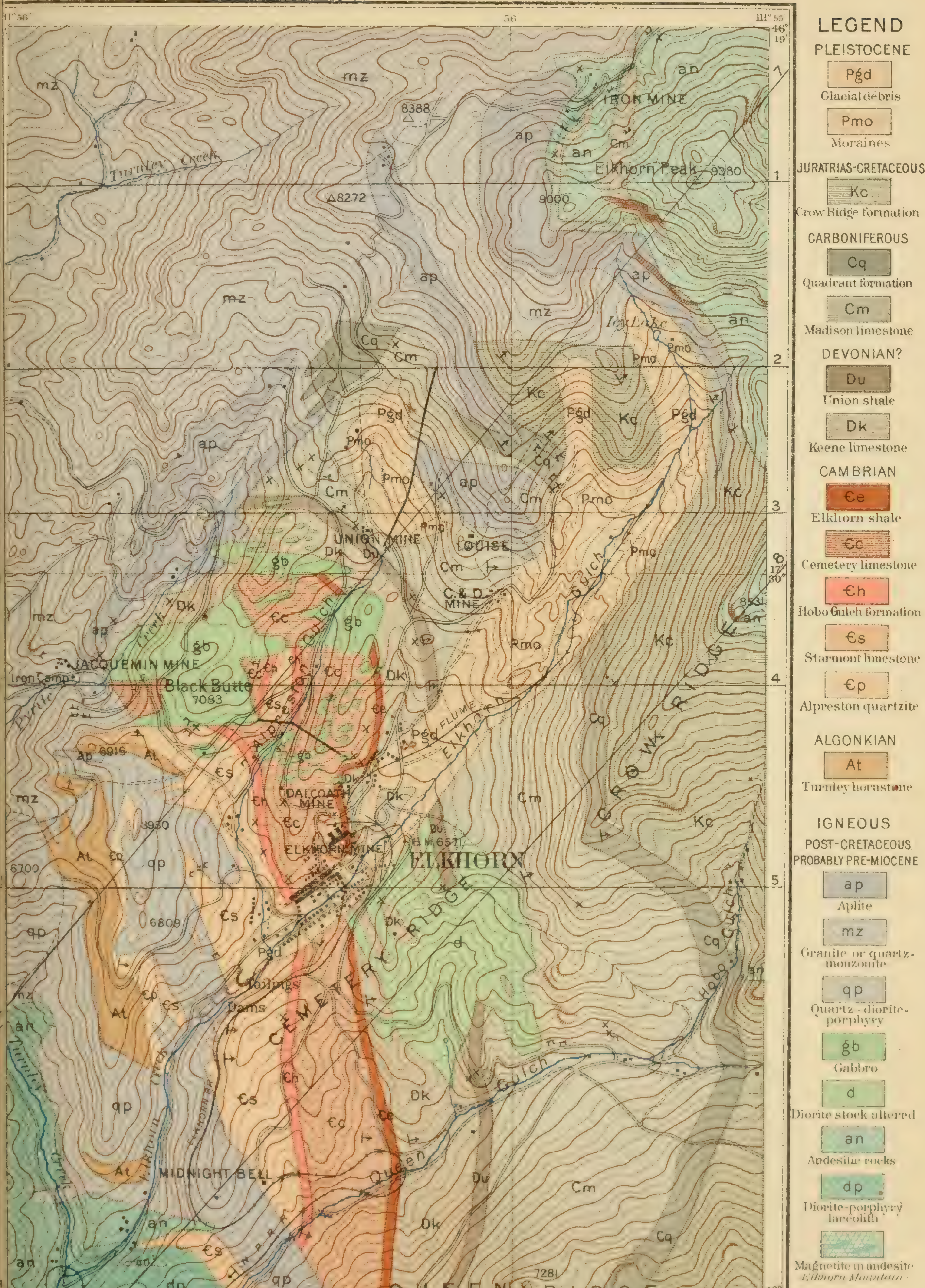
[1] For nomenclature and designation as terrane see Walcott: Bull. Geol. Soc. Am., Vol. X, 1899, pp. 199-244.



GEOLOGICAL MAP OF THE ELKHORN MINING DISTRICT, MONTANA

Scale
0 ½ 1 MILE
Contour interval 50 feet

Walter Harvey Weed, Geologist
Joseph Barrell, Field Assistant

JULIUS BIEN & CO. N.Y.

of great power and probably long duration is represented by the andesitic rocks of Elkhorn Peak and of the mountains running south from Elkhorn toward Bull Mountain. The rocks are clearly similar in character to those seen over parts of the Boulder region, and, as elsewhere, embrace lava flows, tuffs, and breccias. The source of these rocks was some vent lying to the west of Elkhorn. These volcanic rocks were at a later period broken through and probably somewhat metamorphosed by intrusions of diorite-porphyry, which broke off parts of the earlier gabbro mass and chilled against the andesitic rocks. The granite is even later, as is clearly shown in several places by including fragments of earlier igneous rocks. The aplite-granite is still later and is the most recent of the igneous rocks.

The origin of the ore deposits of the region is discussed in a separate chapter. Their source is undoubtedly the igneous rocks, very probably the basic igneous rocks of the district, especially the gabbro.

From the résumé just given it is evident that the district offers exceptional opportunities for studying the relations and relative age of the igneous rocks and the effects of contact metamorphism. With a wide acquaintance with the mountainous region of the State, the writer knows of no other place offering such good opportunities for a study of the effects of igneous intrusions upon other rocks and those of sedimentary origin. Indeed, there is good evidence here that the putting in place of the earlier intrusions has been accomplished with so little disturbance that the effects of the magma upon the disrupted rocks in which it intrudes can be particularly well observed. There is no positive proof of actual assimilation of one rock by another, though the field evidence strongly indicates this, as well as the usual metamorphic action.

All the rocks noted, except the granite and aplite, show metamorphism, most intense near the granite and less so away from it. It is evident that the district has been many times heated, but that the most marked effect is due to the last, the granitic intrusions.

The finding of clearly intrusive andesites low down in Queen Gulch and in the valley of Elkhorn Creek below the town shows that the region was a deeply eroded and mountainous one before these early lavas were poured out, and there is reason to believe that the former extent of these rocks was very much greater than at present. The areal distribution of the rocks of the district is shown on the geological map, Pl. XLV. In the following chapters the rock types and formations will be described and their distribution discussed.

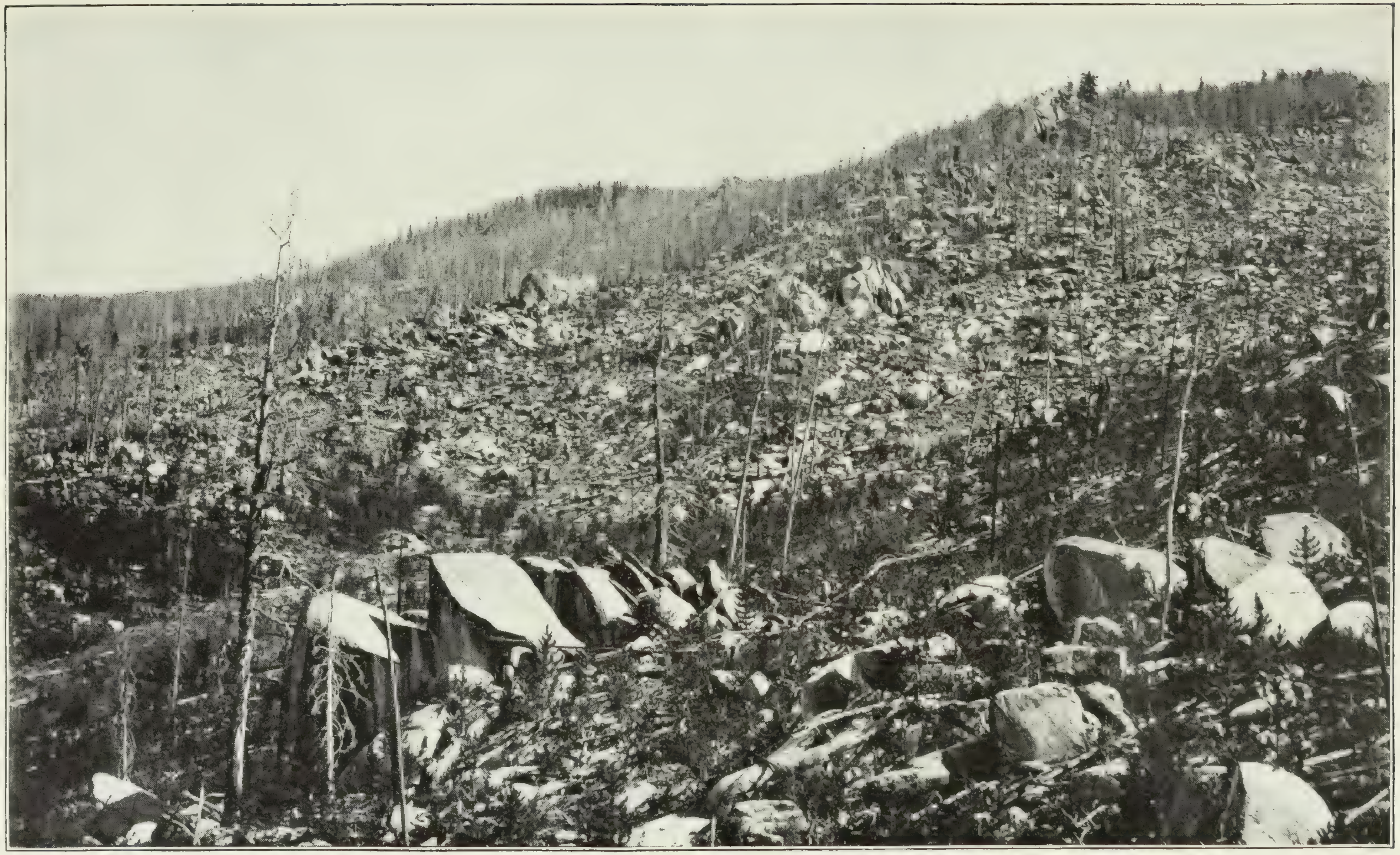
CHAPTER III.

IGNEOUS ROCKS OF THE DISTRICT.

The igneous rocks cover about half of the area shown on the geological map (Pl. XLV) of the Elkhorn district, and, as indicated in the structure sections, they underlie the sedimentary rocks in some areas where the latter are seen on the surface. Their diverse characters, their relations, and their effect upon the sedimentary rocks and upon one another make them the leading feature of the geology of the district. The ore deposits are probably derived from the igneous intrusions, but definite proofs of this connection can not be traced. The igneous rocks are all younger than the sedimentary ones, and if ordinary procedure were followed their description should follow that of the sediments; but, inasmuch as the latter are all altered and metamorphosed by the heat of the igneous intrusions, and hence owe their present characters to them, it has seemed best to give a general description of the igneous rocks first, reserving the account of their microscopical petrography for an appended paper by Dr. Joseph Barrell.

The igneous rocks embrace a number of rock types, varying greatly in appearance and in chemical and mineralogical composition, as a result of original differences in the composition of the magma and of widely varying physical conditions under which the molten material has consolidated into rock. The rocks of Elkhorn and Crow peaks and those seen at the mouth of Queen Gulch are mainly volcanic and represent lava flows and the loose ejectamenta of volcanic eruptions. The other igneous rocks are of intrusive origin and have been consolidated beneath the earth's crust.

The most abundant rock type is one of granitic habit and forms a part of the granite area extending for many miles north, west, and south of Elkhorn. The other rocks are readily distinguished from this and from the andesites by the eye alone, but less readily from one another. With the exception of the gabbro-diorite rocks, which show wide variations in the same rock mass, the rocks are fairly uniform in character throughout each intrusion.



TYPICAL GRANITE AREA AT HEAD OF TURNLEY CREEK.

Showing bowlders due to disintegration along joint planes.

GRANITIC ROCKS.

GRANITE (QUARTZ-MONZONITE).

Definition.—Under the name "granite" are included those coarsely granular rocks, intruded and consolidated at considerable depths below the earth's surface, which have a normal granitic structure and consist of quartz, orthoclase, soda-lime feldspars, hornblende, and biotite. Augite, titanite, and magnetite are present as accessory constituents. The Elkhorn granite is exactly like the granite at Butte in which the copper and silver veins occur. The latter rock has been repeatedly described as a basic granite—one nearly like a diorite in composition. The adoption of the name monzonite for such intermediate rocks makes the new name quartz-monzonite applicable, but the older name "granite," being more generally understood, will be used except in the petrographic description of the rock. The rock is readily recognized, as it is the coarsest-grained rock of the district and contains white feldspars, glassy quartz, black or dark-green hornblende, and dark-brown mica.

Extent and character of surface.—The granite area shown on the map is merely the eastern border of a very extensive granite area lying to the west, extending from Helena on the north to a point 26 miles south of Butte, and from Elkhorn west to the Deer Lodge Valley. This great mass of granite, to which the name "Boulder batholith" has been applied by the writer,[1] is somewhat sharply defined, and with its aplitic forms is the youngest member of the igneous series at Elkhorn, though in many parts of the main area west of Elkhorn it is cut by rhyolite dikes and covered by extrusive masses of that rock. Within the Elkhorn district the granite forms the western flanks of Elkhorn Peak and the rough country west and northwest of the town of Elkhorn. The areas covered by it are readily recognized by the great bowlders which strew the slopes, as shown in Pl. XLVI. The timber, too, is peculiarly indicative in its manner of growth, consisting mainly of the lodgepole pine (*Pinus murrayana*), which rarely attains a diameter exceeding a foot.

Description.—The fresh rock is coarsely granular, of light-gray color, and composed of dark-green hornblende, dark-brown biotite, colorless quartz, and waxy-white and pale flesh-colored feldspar. The grains average about 4 mm. in diameter. The hornblende is more abundant than the biotite. Augite occurs very rarely and is surrounded by paramorphic hornblende. Small grains of yellow titanite are sometimes seen. The rock is not absolutely uniform in appearance, but shows smeary streaks and spots of darker color, which are particularly abundant near the margin of the mass.

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[1] Granitic rocks of Butte, Mont., and vicinity, by W. H. Weed: Jour. Geol., Vol. VII, 1899, pp. 737-750.

The rock is fresh and has suffered little chemical alteration, even where disintegration is prominent.

Chemical composition.—A fresh specimen from the western part of the area shown on the map, analyzed by Dr. H. N. Stokes in the Survey laboratory, gave the following result:

Analysis of granite (var. quartz-monzonite) from near Elkhorn, Mont.

Constituent.	Per cent.
SiO_2	64. 31
Al_2O_3	15. 44
Fe_2O_3	2. 43
FeO	2. 58
MgO	2. 21
CaO	4. 22
Na_2O	2. 71
K_2O	4. 09
H_2O at 110° C	. 19
H_2O above 110° C	. 79
TiO_2	. 71
CO_2	None.
P_2O_5	. 22
S	[a] Trace.
Cr_2O_3	None.
MnO	Trace.
BaO	. 07
SrO	Trace.
Li_2O	Strong tr.
Total	99. 97

[a] Whether S or SO_3 undetermined.

The analysis is typical of quartz-monzonite and corresponds almost exactly with that of the Butte granite. The mineral composition calculated for it is very nearly the same as that of the Elkhorn rock.

Weathering.—The granite disintegrates readily under ordinary weathering processes, and as it is traversed by intersecting joints rounded bowlders thickly cover the ground wherever the slope is sufficiently steep to admit of the removal of the sand into which the rock disintegrates. The result is a peculiarly rugged scenery, typical of granitic rocks in many parts of the world.

Relative to surrounding rocks, the granites are the youngest of the district and have broken across all earlier masses. These relations are fully discussed elsewhere.

APLITE-GRANITE.

The term "aplite" is used to designate granular or finely granular siliceous granites consisting chiefly of alkali feldspar and quartz. The name is here applied to those lighter-colored granites nearly free from augite and biotite, usually somewhat finer grained than the normal rock, and occurring as dikes and intrusions in it or in the rocks near its border. The rock is, when fresh, creamy white, slightly finer grained than the granite, of sugary texture, and contains very few and small grains of biotite and hornblende. The rock varies greatly, however, in texture and appearance, and, as shown in another chapter in discussing its relationships, is possibly locally enriched by material absorbed and assimilated from the rocks with which it is in contact. It varies from very finely granular structure to a pegmatite. It weathers in rounded surfaces, but does not form the bowlders characteristic of the quartz-monzonites. It is subject to disintegration, and when so altered is easily quarried and dressed.

An analysis made by Dr. Stokes showed the following composition:

Analysis of aplite from Elkhorn, Mont.

Constituent.	Per cent.
SiO_2	76.26
Al_2O_3	12.94
Fe_2O_3	.69
FeO	.13
MgO	.17
CaO	1.10
Na_2O	2.73
K_2O	5.26
H_2O at 110° C	.17
H_2O above 110° C	.43
TiO_2	.11
CO_2	None.
P_2O_5	.06
S	*a* .01
Cr_2O_3	None.
NiO	None.
MnO	Trace.
BaO	.07
SrO	None.
Li_2O	Trace.
Total	100.13

a Total S.

DIORITE-GABBRO GROUP.

These rocks form a series in which gabbro and diorite form the end members, with rocks of intermediate character between. The areas occupied by each rock have been mapped separately, but the smaller intrusions near the town are of intermediate character, while the geological evidence indicates that they are all parts of one great mass underlying the altered sedimentary rock seen on the surface.

GABBRO.

Definition.—A gabbro is a granular crystalline rock, consisting essentially of lime-soda feldspar and pyroxene (commonly augite). The Elkhorn gabbro is a dark bluish-gray rock, varying from fine to coarse grain. The most basic variety, found at Black Butte, shows a felted mass of satiny labradorite crystals, with irregularly rounded grains of augite and considerable magnetite. Gabbros commonly show decided variation in mineralogical composition in parts of one mass, and the local modifications might be described as special types. The basic type just noted varies to one showing hornblende and biotite replacing augite and showing some quartz. The texture of the rock is particularly well shown on weathered surfaces, on which the dark augite stands in relief above the dull-gray feldspar. In the coarsest-grained forms the augite grains are so large and abundant as to give the rock a strongly porphyritic appearance. In the finer-grained forms the augite grains are minute and the rock has a pepper-and-salt appearance and texture.

Chemical composition.—An analysis of a typical form of the rock, from Black Butte, has been made in the Survey laboratory by Dr. H. N. Stokes, with the following result:

Analysis of gabbro from Black Butte, Elkhorn, Mont.

Constituent.	Per cent.	Constituent.	Per cent.
SiO_2	47.44	CO_2	None.
Al_2O_3	18.21	P_2O_5	.68
Fe_2O_3	5.37	S	*a*.03
FeO	6.05	Cr_2O_3	None.
MgO	5.53	NiO	None.
CaO	9.98	MnO	.06
Na_2O	2.58	BaO	.08
K_2O	1.17	SrO	.08
H_2O at 110° C.	.13	Li_2O	Trace.
H_2O above 110° C.	1.08	Total	99.85
TiO_2	1.38		

a Undetermined whether sulphide or sulphate.

Occurrence.—Gabbro occurs in several small intrusive masses, apparently breaking up through sedimentary rocks and forming irregular masses called stocks. The largest area, which is a half mile across, is that of which Black Butte is the most conspicuous point. A lesser stock occurs a thousand feet farther north, and another to the east. The ridge between Elkhorn and Preston shows many exposures of an intermediate gabbro-diorite rock, which are thought to be the tops of dike-like intrusions connecting with a general parent mass below.

The rock resists weathering well, but does not commonly form exposures, except on Black Butte, where it occupies a conspicuous position, being visible for many miles around. In the smaller outcrops the rock decomposes somewhat readily, although its resistance to weathering is generally in marked contrast to the more easily altered diorite. Black Butte shows a massive exposure of great blocks and loose masses 5 to 10 feet across, the actual summit being a point with sharp western and precipitous eastern faces. The precise limits of the intrusions are defined with difficulty, owing to the presence of waste from above. The smaller masses show as low reefs or groups of bowlders, seldom prominent.

The Black Butte mass contains many included fragments of sedimentary rock—limestone altered to a mass of epidote and garnet—the sediments about the margin of the gabbro and those through which the dike have come up being all intensely altered by metamorphism. This and the attitude of the strata, which appear to dip inward, all indicate that these different exposures are parts of one mass underlying the entire area in which the exposures are found. The sediments are evidently greatly shattered and greatly metamorphosed, and probably form a relatively thin capping over the main core or reservoir of this rock, the smaller intrusions rising from it and through the cover like the branches of a tree.

DIORITE.

In the workings of the Elkhorn mine and in the railway cut east of the town a very fine-grained dark-gray rock is found which closely resembles the finer-grained forms of gabbro, but which, when studied under the microscope, is found to be diorite. The rock masses mentioned are offshoots of a mass lying east of Elkhorn.

Definition.—Diorite is a plutonic rock which varies somewhat in texture, but is always granular, and consists essentially of soda-lime feldspar, and hornblende. The Elkhorn rock is rather basic and is allied to the gabbros. In the freshest rocks seen it is a dark gray and not unlike the gabbro of Black Butte, but in fresh fracture is easily recognized, as the gabbro shows no white feldspar and is of a uniformly gray tint, while the diorite, when closely examined, is seen to consist of a mass of dark-colored hornblende, augite, and bronzy biotite grains, held together by a matrix of white feldspar, though this is less apparent in the more common, finer-grained forms of the rock.

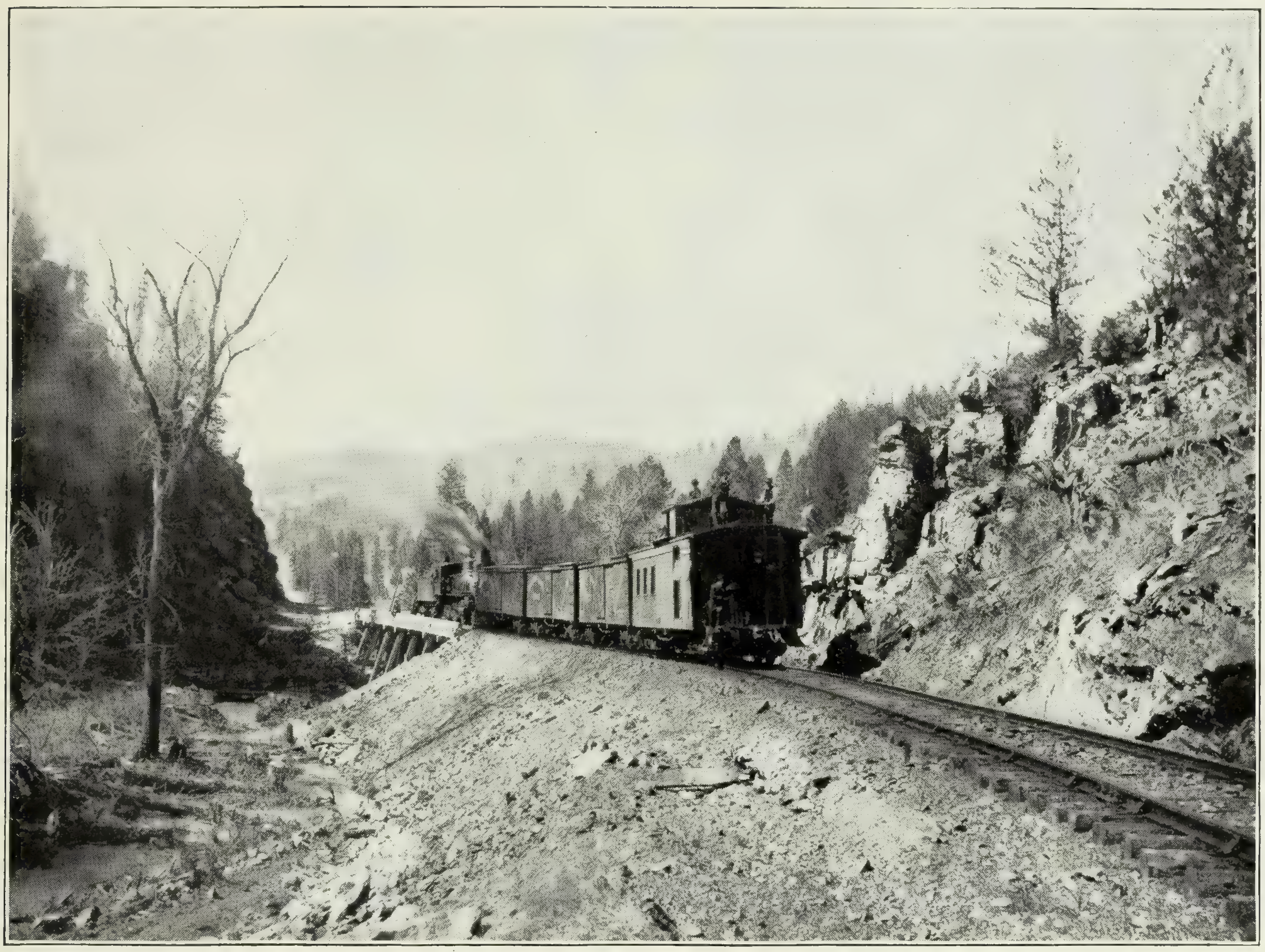
Extent and area covered.—The main diorite area occurs east of the town, forming the ridge and the shallow, grassy amphitheater north of Queen Gulch. The rock weathers readily and decomposes to a soft and porous mass, so that, though exposures are abundant, fresh unaltered material is hard to obtain. The dike rocks also weather readily and are commonly concealed by the limestone débris and soil. The area covered by it is about 3,000 feet across and somewhat longer in the direction of the strike of the stratified rocks, the shape of the intrusion evidently being influenced by the attitude of the sedimentary beds.

The exposures in the railroad cut for one-fourth mile south of the station show an alteration of this diorite. Nucleal masses are seen surrounded by soft and much crackled white, pale-yellow, or yellowish-green alteration products. The same phenomena were observed in the mine workings, 1,250 feet below the surface. They show that the cause of alteration is a deep-seated one, and that it is not a mere surface phenomenon. In the railroad cut just mentioned the altered diorite is lacking southward, but limestones appear cut by diorite dikes, six dikes, varying from 5 to 60 feet in width, being noted intrusive in the upturned strata in the second quarter mile.

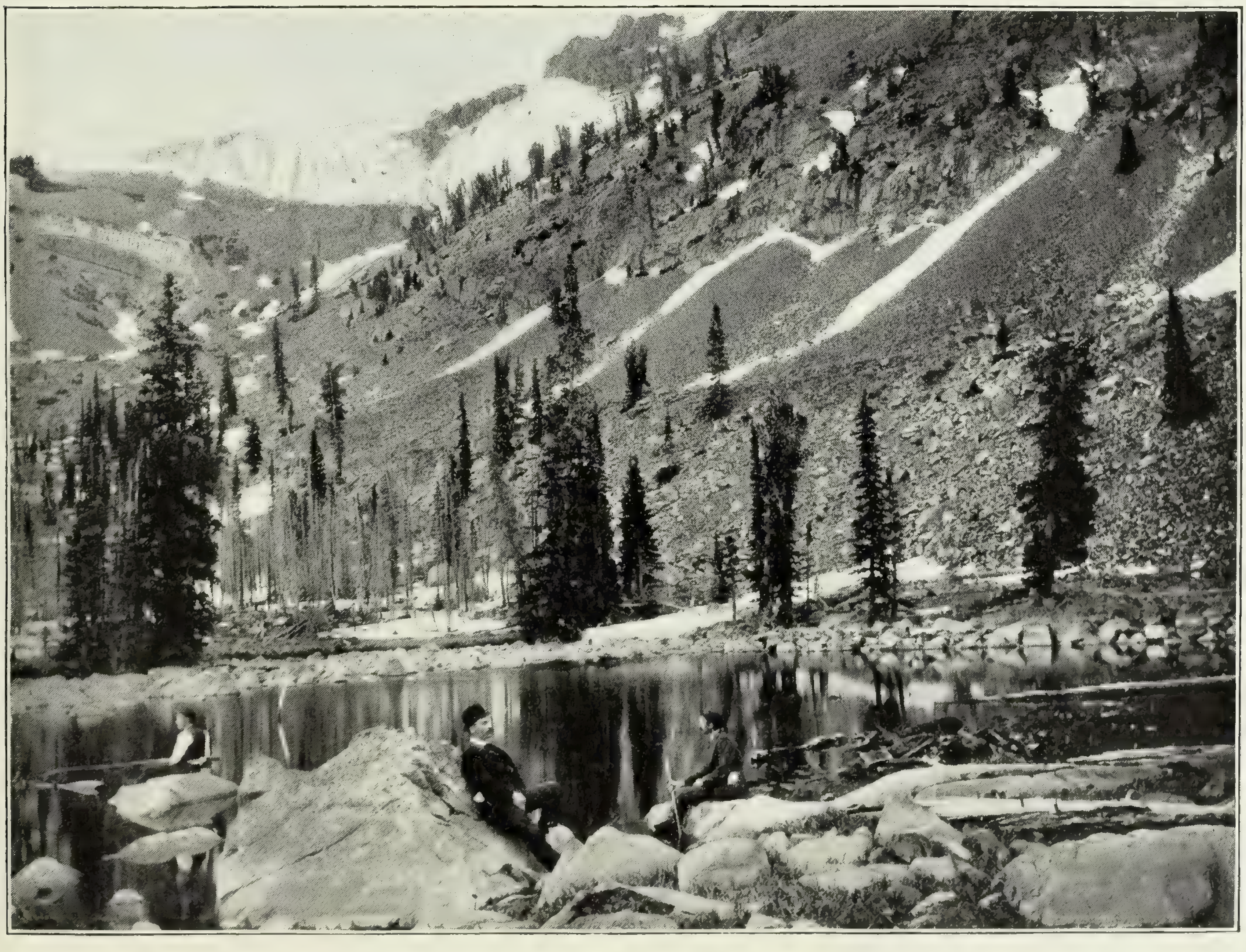
QUARTZ-DIORITE-PORPHYRY.

Definition.—Quartz-diorite-porphyry—using the name "porphyry" in the broad sense adopted by the Geological Survey to designate a porphyritic texture—is a fine-grained rock having the composition of a quartz-diorite (that is, composed essentially of plagioclase feldspar and free quartz, with accessory orthoclase and ferromagnesian minerals), which contains phenocrysts or large distinct crystals, usually of plagioclase and less commonly of augite or other iron magnesian silicates, in a finely crystalline matrix.

Extent and character of surface.—The Elkhorn quartz-diorite-porphyry covers a considerable area in the southwestern portion of the district, where it forms the ridge between Turnley and Elkhorn creeks and the sharp ridge to the east where the railroad crosses from Queen to Elkhorn gulches. It forms talus-covered slopes, in part wooded, but of characteristic appearance, as shown in Pl. XLIV, so that the area covered by it is in a general way easily discriminated from that of the other rocks. The mass is cut through by both Turnley and Elkhorn creeks, exposing a section 800 feet deep across the mass. The gently sloping summit west of the mouth of Alpreston Gulch is covered by soil and vegetation, so that good exposures are not common.



A. POINT OF ROCKS, SHOWING GORGE CUT IN ANDESITES BELOW TOWN OF ELKHORN.



B. ICY LAKE AND MARBLE CLIFFS, ELKHORN PEAK.

The white area is an included mass of marble in andesite; the cliffs on the right are highly altered Mesozoic rocks.

ANDESITIC ROCKS.

Definition.—Andesites are volcanic rocks of porphyritic or felsitic texture, whose crystallized minerals are plagioclase with either biotite, hornblende, or augite, or any two, or all three of the minerals. The andesitic rocks embrace a wide variety of types of both intrusive and extrusive origin. They differ greatly in appearance, but are all closely related in composition and genesis and form part of the great formation covering large areas in the Crow Creek Mountains north and east of Elkhorn; they also form the hills to the southwest of the town and the long and high ridge known as Bull Mountain, which is a continuation of these hills. Collectively they represent the products of a single period of vigorous volcanic activity. Here, as elsewhere in the State, these rocks constitute great mountain blocks, which have been piled upon the earlier rocks in great masses, and which were probably parts of cones now dissected, so that the existing mountains are merely residual masses of the old volcanoes.

Extent and character of surface.—These rocks constitute the highest and most rugged peaks of the district. They form great amphitheaters, where steep cliffs and projecting buttresses are in strong contrast to extensive talus slopes formed by the débris of the rocks. In general, the rocks form sharply accentuated topographic features. In the gorge below Elkhorn they are cut by the creek in the narrow canyon with abrupt walls, seen in Pl. XLVII, *A*. Along Elkhorn and Crow creeks the rocks form the highest summits of the whole range.

Description.—The rocks show a wide range in mineral composition and texture, varying from quartz-diorite to diabase and from andesite-porphyries to tuffs, but are mostly typical andesitic rocks of various kinds. Owing to the reheating and metamorphism due to the proximity of the great granitic mass to the west, the original character of the rocks has been obscured, and their present texture and mineralogical composition are largely the result of such metamorphism. The most typical rocks are dense, dark colored, tough, and elastic. They vary from light gray to dark in color and from rocks devoid of phenocrysts to distinctly porphyritic forms, the latter being the most common. Despite the metamorphism to which they have been subjected, they still exhibit evidence of their original character as lava flows, breccias, tuffs, and intrusive sheets. They are dense, fine-grained rocks, with microcrystalline texture, and commonly show phenocrysts of white labradorite-feldspar, and more rarely of augite and hornblende. The determination of the predominant type as andesitic in habit is confirmed by the careful petrographic study made by Dr. Barrell, and a full description of them is given in the appendix.

Chemical composition.—The chemical composition of these rocks probably presents the same variations shown in their mineralogical character. But two analyses have been made: The first, that of the normal andesite; the second, that of the altered andesite.

Analyses of andesitic rocks.

Constituent.	E 35.	E 42.
SiO_2	54.50	59.64
Al_2O_3	17.97	16.64
Fe_2O_3	[a] 8.55	2.33
FeO	([b])	4.35
MgO	3.37	2.10
CaO	9.36	4.59
Na_2O	2.34	3.31
K_2O	1.62	4.16
H_2O at 110° C	.14	.14
H_2O above 110° C	.96	.69
TiO_2	.94	1.08
CO_2	None.	None.
P_2O_5	.31	.49
S	[a] .63	[c] .01
Cr_2O_3	None.	None.
MnO	Trace.	Trace.
BaO	.06	.10
SrO	.05	.05
Li_2O	Trace.	Trace.
Total	100.80	99.68

[a] Contains both pyrite and pyrrhotite; amount undetermined, but between 1.59 Fe_7S_8 and 0 FeS_2, and 1.19 FeS_2 to 0 Fe_7S_8.

[b] FeO can not be directly determined. The 8.55 per cent Fe_2O_3, including Fe_2O_3, is equivalent of FeO and sulphides. FeO lies between 5.39 and 6.46, and Fe_2O_3 between 1.19 and 0.

[c] Undetermined whether sulphide or sulphate.

Weathering.—The andesite was traversed by a close system of fine joints that break on weathering into sharp and angular débris. On the highest and most rugged mountain slopes the individual blocks are several feet across and the slope exposures form rude stairways, while the solid rock forms rocky buttresses that extend beyond the general cliff wall or jut out from smooth talus slopes. In the exposures at lower elevations the solid rock forms broken cliff masses, as shown in Pl. XLVII, *A*, the network of closely spaced joints causing the rock to break on weathering into rather small fragments. In general the rock breaks into fine débris composed of pieces but a few inches across and forming great talus slopes which, where steep, are commonly bare of vegetation, but where flatter are covered by grass and a scattering growth of timber.

The rock is readily altered by ordinary weathering, the augite-biotite and other dark minerals changing to chloritic aggregates and the feldspars clouding from incipient kaolinization. This alteration is so widespread that it is impossible to procure specimens of the perfectly fresh rock. On the other hand, the final alteration of the rock results in merely a thin skin upon the surface of the fragments. The rock is very resistant and with the possible exception of quartzite offers more resistance to ordinary disintegrating agencies and to the wear and tear of stream transportation than any other rock known in the State.

DIORITE-PORPHYRY.

In the extreme southwest corner of the district there is a mass of fine-grained gray rock which is distinguished from the andesites with which it is associated by its more crystalline texture, spotted appearance, and uniformity of character. It is well exposed in the railroad cut at the mouth of Turnley Gulch, and also in the lower line in Queen Gulch. The exposure seen in the railroad loop at Turnley Gulch shows it to be intrusive in andesitic rocks. The rock is a diorite-porphyry of conspicuous appearance, owing to its markedly spotted or mottled character, which results from the presence of dark clusters of hornblende and biotite, which, with crystals of labradorite, lie in the fine-grained gray groundmass. The rock is uniform throughout the entire mass, the upper portion showing a slightly darker or bluish tint and resisting weathering better, so that the rock forms bold ledges. The upper 100 feet show distinct lamination planes parallel to the andesitic contact.

CHAPTER IV.

DESCRIPTION OF THE SEDIMENTARY ROCKS.

The stratified rocks cover a relatively small part of the district, and their normal characters have been in large part obliterated by the metamorphism they have undergone as a result of the heat and mineralizing action of the igneous masses which have broken through them. As already noted, the altered strata are, however, continuously traceable into the unaltered formations which make up the great folds forming the mountain ridges east of Elkhorn and extend to the valley of the Missouri River. Within the limits of the district it is difficult, if not impossible, to identify all the horizons recognizable in the unaltered area, and its importance did not justify the time necessary to trace out such connection. In general, the broader distinctions recognized in the unaltered series can be discriminated, while the Carboniferous limestone is identified by fossils in the immediate vicinity of the granite contact, and the overlying quartzites have been followed south to unaltered strata.

The rocks are all tilted, and the areas shown on the map include blocks broken off from the main body, though in general the masses are all part of the eastern flank of a broad fold composed of all the sedimentary strata from those of probable Algonkian age to the Cretaceous. The beds within the district are therefore not horizontal, but have a general eastward dip at angles of 30° to 55°. The general lack of fossils and the metamorphism of the rocks make the determination of their age almost impossible save by correlations and by tracing them out to the unaltered areas.

The sedimentary series at Elkhorn may be seen in an unaltered condition in the hills a half mile or more southeast of the town. The sequence there seen does not differ materially from that which prevails in the neighboring mountain ranges. A few notes upon the correlation of the formations are therefore given. The Algonkian beds are part of the Belt terrane, from which fragmentary fossil remains have been reported.[1] The Cambrian rocks of the neighboring ranges contain abundant fossils which prove their Middle Cambrian age, neither the Lower nor Upper Cambrian faunas being represented. The Silurian is commonly absent or represented by nonfossiliferous beds, the fossil collections from certain localities indicating Silurian tendencies. The Devonian is known by typical fossils from the dark Jefferson limestones of the Little Belt region and from the Three Forks shale of the Gallatin Valley. The Triassic is not recognizable. The extensive red sandstones which represent this age in Wyoming, occurring in the Yellowstone Park, though devoid of fossils, thin out and disappear northward, and have not been recognized within 100 miles of Elkhorn. The Jurassic, which, though sometimes less than 100 feet thick, is commonly exposed throughout the State and is almost everywhere fossiliferous, has not been positively identified in this district. The Cretaceous rocks of the State are commonly divisible into the usual well-marked groups. At some localities, however, the abundance of arenaceous beds makes lithologic distinctions impossible, and this and the absence of fossil remains at Elkhorn make subdivision or correlation of formations quite impossible. There can, however, be no doubt of the Cretaceous age of the beds when the section is compared with sections made in neighboring mountain ranges.

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[1] Pre-Cambrian fossiliferous terranes, by C. D. Walcott: Bull. Geol. Soc. Am., Vol. X, 1899, pp. 199-244.

For purposes of mapping, the Elkhorn rocks have been divided into lithological units, mostly well defined and entitled to rank as formations, several of them corresponding to formations recognized in the unaltered rocks of neighboring districts. An attempt was made to measure a complete section embracing all the beds from oldest to youngest. There are, however, no continuous exposures, and the thicknesses herein adopted are estimates based upon such measurement as it was possible to make by pacing horizontal distances, all elevations being determined by aneroid and the results checked by the map. Several partial sections have also been used in making an average. In the folding and probable uplifting to which the strata have been subjected, as a result of dynamic activity before and during igneous intrusions, there has been some slipping along bedding planes, and certain shale formations are missing in the Elkhorn section.

Throughout the Paleozoic series the contrasting characters of successive beds permit the subdivision of the series even when the original characters are entirely destroyed. In the Mesozoic series, of which at least 2,000 feet exists in the district, notably on Crow Ridge, the rocks were originally impure shale and sandstones, grading into one another and seldom presenting sharply contrasted formations. These are now altered to tough, dark-colored, very dense hornstones, which so closely resemble one another that a classification in the field is almost impossible.

For the various reasons given, the age distinctions in the following table are only approximate, though the general characters and succession of the strata are evident.

Generalized section of the sedimentary rocks of the Elkhorn district, Montana.

Age.		No.	Name.	Feet.
Cretaceous		11	Crow Ridge beds: hornstones, adinoles, and quartzites; top capped by andesites of Crow Peak.	1,680
Carboniferous	Neocarb.	10	Quadrant formation: sandstones and quartzites with interbedded limestones altered to a lime silicate hornfels.	380
	Eocarb.	9	Madison limestone: in places altered to marble.	1,900
Devonian?		8	Union shale: black shales and hornstone	130
Cambrian		7	Keene limestone: in part argillaceous	500
		6	Elkhorn hornstone	100
		5	Cemetery limestone: includes the white granular foot-wall limestone of the Elkhorn lode and the underlying blue limestones.	650
		4	Hobo Gulch shaly limestone: includes characteristic limestone flags.	153
		3	Starmount limestone: mostly argillaceous	600
		2	Alpreston quartzite: probable equivalent of Flathead quartzite.	125
Algonkian?		1	(*b*) Turnley quartzitic hornstone	200
			(*a*) Turnley shale: red sandy; indurated	200
			Basal beds concealed by andesitic lavas.	

ALGONKIAN ROCKS.

Turnley hornstones (*Spokane shale?*).—The Turnley beds are the oldest strata of the region. They occur only on the slopes above the Turnley placer in the southwestern part of the district, where they form a block separated from the main mass of stratified rocks by a tongue of granite. In color, composition, and relation to the overlying quartzite the rocks correspond to the red Spokane shale of the Belt terrane seen at Whitehall, 20 miles south, at Townsend to the east, and at Helena on the north. The lower, softer strata consist of rocks that weather to a good soil, forming open, grassy slopes. The overlying quartzitic hornstones are more resistant and their débris is conspicuous on the surface.

The lower division is 200 feet thick, and consists of shale metamorphosed to a very dense hornstone composed of light-brown biotite and quartz. A bed of impure iron ore 20 to 30 feet thick occurs in the middle lower part of the formation.

The quartzitic hornstones overlie the basal beds just noted and are 200 feet thick. The rocks, though well bedded, are very dense and hard and are of a gray-black color, so that they closely resemble the andesites. The texture is finely saccharoidal, the fracture conchoidal. The rocks are well exposed in a road cutting near the southern end of their outcrop. Microscopical examination shows the rock to consist of quartz and a small amount of olive-green mica.

CAMBRIAN ROCKS.

Alpreston quartzites (*Flathead quartzites*).—The quartzites are 125 feet thick, nearly white in color, and owing to their superior hardness are well exposed, forming the crest of the hill west of the town. The rock is an altered sandstone and is correlated with the Flathead sandstone, the base of the Cambrian series of the State.[1]

Starmount limestones.—These limestones are separated from the beds just described by an intrusion of granite-porphyry, but correspond in character and position to the Meagher limestone of the Little Belt section,[2] though positive identification is impossible and it seems best to give the formation a local name derived from that of a mine in it. The lowest beds consist of about 250 feet of light-gray, thinly bedded argillaceous limestone, which is rather soft and weathers down in even slopes beneath the first persistent limestone cliff of the sedimentary series. In the Elkhorn exposures the rocks are more or less metamorphosed and commonly altered to a light greenish-gray hornfels of great hardness. The upper member of the series, comprising 350 feet of rocks, differs from the lower chiefly in being more massively bedded and of a darker color, the rock being mottled with spots of a darker color and containing less silica and clay than the lower beds. The rocks resist weathering better than the underlying, more shaly strata, and form bluffs which are often conspicuous topographic features. Their best development in the Elkhorn district is on the hillside, south of the dams in which the mill tailings are caught (Pl. XLVII, *A*). At this place they are well exposed in the steep slopes above the railroad line. The largest exposure of the formation shows the strata to be separated from the underlying Turnley series by a quartz-diorite-porphyry intrusion several hundred feet in breadth, so that the exact relation of the two formations is nowhere absolutely determinable. If the correlation assumed be correct, the Starmount limestones must have been underlain by a considerable thickness of shale, corresponding to the Wolsey shale, but the intrusive mass of porphyry now found below the Starmount limestone was probably intruded also in the shale and now conceals it. In the southwestern part of the district a block of Starmount limestone has been overturned by an intrusion of andesite and now lies between the latter rock and a diorite-porphyry intrusion. This fragment is 400 feet in thickness, and has been altered throughout to an aggregate of garnet, augite, wollastonite, and feldspars. From a distance the rocks at this place still have the appearance and the structure of light-gray, massively bedded limestones, though on near view it is seen that the bedding planes have been entirely obliterated, and that the original stratified nature is recognizable only by slight changes in color or by differential weathering, which develops a thinly laminated structure on exposed surfaces. Similar altered rocks of the same age are seen in Alpreston Gulch, northwest of the town, and at Black Butte, where the rocks have been intensely altered and fragments occur in the gabbros. The description of these included fragments and remarks on their significance will come more properly in the account of contact phenomena given in the last chapter of this paper, to which reference must be made for details of their mineralogic characters.

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[1] See Geology of the Little Belt Mountains, by W. H. Weed: Twentieth Ann. Rept. U. S. Geol. Survey, Part III, 1900, pp. 284–287, for discussion of the Cambrian formations and their relations to the rocks of other ages.

[2] Weed: loc. cit., p. 285.

Hobo Gulch lime-shale.—This name is applied to a well-marked group of strata seen in the railroad cuts near the tailing dams and in Queen Gulch. It is an important horizon for mapping, as it possesses easily recognizable characters and separates two thick and somewhat different limestone formations.

The lowest member of the series consists of 18 feet of shales which have no conspicuously marked characteristic. A limestone nearly 100 feet in thickness succeeds the shale. The rock is nearly black, with abundant smooth joint planes. On weathering it forms angular, smooth, dark débris by which the horizon may frequently be traced. The uppermost part of the formation is the "crinkled limestone," a 35-foot bed of banded cherty limestone, thinly bedded, and with the cherty material in the form of lenses averaging two-thirds of an inch in thickness and 1 or 2 inches in length. This is the most characteristic bed of the Cambrian series wherever it has been observed in Montana, and commonly consists of pure limestone with lenses of cherty material. The crinkled appearance is not due, as might be supposed from the Elkhorn exposures alone, to a bending of these rocks, in which the limestone would be curved about the harder siliceous lenses, as this characteristic has been noted where the beds are perfectly horizontal and show no folding whatever. In weathering, the limestone is more readily attacked and as a consequence the impure, cherty, or argillaceous lenses weather in relief and the bowlders present a rough surface with lozenge-shaped depressions. These limestones are so much harder than the strata adjacent to them that the horizon is readily distinguishable despite its small thickness and the fact that it does not present any marked topographic relief. The underlying Starmount limestones often show the same crinkled appearance, so that in identifying the horizon it is necessary to look for the underlying shale. This formation seems to correspond fairly well in position to that of the Pilgrim limestone of the eastern Montana Cambrian exposures, in which case the basal shale would be the Park shale horizon. This correlation is, however, not based upon anything more than lithological sequence.

Cemetery limestone.—This limestone, named from its occurrence at the Elkhorn cemetery, consists of 650 feet of beds, all of which are true limestones. The lower 70 feet consist of blue limestones, followed by 50 feet of dark-blue granular limestone, weathering with a lighter-gray surface and showing sections of brachiopods and crinoid stems. Above this occurs a great thickness of light-blue, thin- to thick-bedded limestone, sometimes mottled with dark-blue spots in a lighter ground. In Queen Gulch the lower beds are somewhat altered by contact metamorphism and show a decidedly crystalline texture. The same also is true of the rocks exposed in the hillside west of the Elkhorn mill, where the rocks are very dark and crystalline and break into small blocks whose dark color presents somewhat the appearance of a basic eruptive when seen from a distance. It seems hardly possible that this dark color can be due to contact metamorphism, inasmuch as the tendency of heat would be to drive off the organic material to which this color is due. This being true, it is hard to explain a decided difference in the appearance of the rocks near the Elkhorn mill and those in Queen Gulch, unless the latter is really the lower limestone of the Hobo Gulch formation. The uppermost 100 feet of the Cemetery limestone includes the thin- and thick-bedded white or light-gray limestones, showing a crystalline, granular texture. This bed varies to a straw-yellow dolomitic marble, which constitutes the foot wall of the Elkhorn mine. It may be seen on the surface in Queen Gulch and in the railroad cut east of the town.

Elkhorn hornstone.—The Elkhorn hornstone is seldom seen in good surface exposures, but its location has been determined by numerous prospect pits made to trace out the bedding plane between it and the underlying limestone, the horizon on which the ore bodies of the Elkhorn mine occur. The rock is well exposed in a hanging-wall crosscut of the Elkhorn mine, consisting of a series of thin-bedded strata, varying in composition from nearly pure, extremely dense, and fine-grained quartzites to calcareous and argillaceous shales. The rocks are indurated and metamorphosed and in the mine are really hornstones. The thickness is estimated at 40 feet, though in the mine a crosscut 120 feet long is driven through these and closely similar calcareous rocks which dip east at 40°.

SILURO-DEVONIAN ROCKS.

Keene limestone.—This formation consists of limestone beds which are so poorly exposed, owing to a covering of morainal and other débris, that their thickness is not accurately known, but is estimated at 500 feet. The basal beds consist of bluish-gray limestone, usually altered to a fine-grained marble. The upper strata are more thickly bedded and lighter in color. The formation is, as a whole, slightly arenaceous and, though devoid of fossil remains, is believed to include the uppermost or Yogo limestone of the Cambrian series and the overlying dark-colored granular Jefferson limestones of Devonian age.

Union shale.—This readily recognizable horizon comprises a basal bed of black shale 30 feet thick, overlain by a metamorphosed siliceous limestone that is about 100 feet thick. The latter rock is altered to a light-colored jaspery material that weathers in smooth-surfaced, angular blocks, whose outcrop sometimes forms low ridges. The formation, like that below it, is broken by igneous intrusions, and no continuous exposures occur. It is seen in numerous prospect holes and may commonly be recognized by the dual character. The best exposures are three-fourths of a mile north of the town, where the shale has been fruitlessly prospected for coal.

Near the igneous rocks the formation is so altered as to be unrecognizable by its lithological character alone. Near the Union mine, at the head of Alpreston Gulch, it is altered to a light-colored rock. In Queen Gulch, near the Cemetery Ridge diorite stock, the shale is altered to dark purplish-red hornstone, while the overlying siliceous limestone is an exceedingly hard, light-gray hornstone, much fractured by minute jointing. The horizon corresponds to the Three Forks shale, a Devonian horizon.

CARBONIFEROUS ROCKS.

Madison limestone.—The great limestone series known as the "Madison formation" is conspicuous in the Elkhorn district, as it is elsewhere in the State of Montana. A conservative estimate of the total thickness in the Elkhorn region is 1,900 feet. The rocks consist here, as elsewhere, of limestones which in the lower half of the formation are dark colored and sometimes argillaceous, though usually the dark color is due to carbonaceous material. The middle portion of the series consists of very pure limestones, which are very resistant to weathering and usually form white cliffs that are conspicuous features of the landscape. In this district, however, the limestones have been recrystallized into marbles, and as a consequence of their very coarse texture and friable nature weather somewhat readily, and hence do not form very striking exposures. The best section is found on Crow Ridge, northeast of the town of Elkhorn. The series contains fossil remains, even in the marbleized areas, and these show the usual Lower Carboniferous forms common to the formation throughout the State. The following section has been made by Dr. Barrell:

Section of the Madison limestone on Crow Ridge

	Thickness in feet.
9. Somewhat siliceous limestone	170
8. Light-colored andesitic sheet	1
7. Concealed limestones	225
6. Light-blue limestone with dark-blue circular spots	7
5. Pale-blue limestone with white seams and small crinoid stems	370
4. Pale-blue massive limestone, forming at this point the lowest prominent outcrop	148
3. Blue limestone with thin cherty seams	715
2. Blue limestones, somewhat banded, with large crinoid stems and white chert bands prominent on weathered surfaces	66
1. Blue limestones containing near the middle, at this point, beds holding abundant needle-like crystals of tremolite	200
Total	1,902

A section made by the writer in the hills east of Elkhorn Creek, a few miles below the town, where the beds are unaltered, shows that the rocks are similar in character, and as the section goes up into the quartzite of the Quadrant formation and includes the red shales, which seem to be lacking in the section as exposed on Crow Ridge, it is given in detail:

Section of the Carboniferous strata exposed in the hills east of Elkhorn Creek, 3 miles below the town.

	Thickness in feet.
23. Quartzite, rather coarse grained, dark colored on weathering, and very resistant	10
22. Limestone, light gray in color, the outcrop forming a massive ledge	5
21. Sandstone, impure and shaly, reddish in color	5
20. Quartzite, gray, dense, outcrop marked by trees	15
19. Limestone, gray, thinly and irregularly bedded, cherty	4
18. Quartzite in heavy beds varying in color and texture; the rock often shows smooth jointing and the weathered surface is knotted	35
Quadrant formation:	
17. In exposure a soil shows sandy clays of reddish or brown color	15
16. Limestone, gray and impure, and forming part of a clay-shale series	1
15. Shale, red and purple	6
Igneous intrusion of basic augitic rock, much decomposed	5
14. Quartzite, white to buff in color, and occasionally pink	3
13. Limestone shale, grading into limestone at base, thin laminæ of limy material alternating with arenaceous material	8
12. Limestone, light gray in color; weathers with rough surfaces, jointed, and showing masonry-like outcrop	4
11. Shale of buff to pink color; laminæ from one-third to one-eighth of an inch thick; color possibly due to igneous intrusion beneath it	3
Igneous intrusion of augitic rock	6
10. Limestone, the upper 4 feet forming a ledge outcrop	12

	Thickness in feet.
9. Impure limestone, in part red and dolomitic, and carrying sand	30
8. Red limestones, the color due to blotches and included masses of reddish material in gray or buff limestone	10
7. Limestone, forming rough ledge of pink-gray color with knotty and somewhat open-textured outcrop	10
6. Sandstone, red and arenaceous, weathering into red clays, good exposures being rare	60
Madison limestone:	
5. Limestone, gray, cherty, brecciated	10
4. Limestone, gray, thinly bedded (1½ to 3 feet), of a slaty or blue color, carrying abundant chert fragments with seal-brown surface	30
3. Limestones of typical Madison aspect, rather thickly bedded, showing blocky fracture and carrying large, irregular-shaped fragments of chert; the upper portion somewhat thinly bedded	255
2. Limestone, very massive, without traces of bedding, the upper 30 feet of dark-blue or gray, very dense, cherty limestone, emitting a fetid odor when struck with a hammer	80
1. Limestone, dark gray, weathering to a buff gray, and with a peculiarly guttered surface; carries occasionally black cherty masses of ovoid shape and shows *Zaphrentis*, crinoid stems, and corals	80

Quadrant formation.—The Quadrant formation corresponds closely in its stratigraphic relations and lithologic composition to the rocks known by this name elsewhere. Owing to the intense alteration to which the rocks have been subjected in Crow Ridge, the formation consists there of quartzite and hornfels; but if the same series be studied at the head of Queen Gulch, the rocks will be found unaltered. The sequence and character of the basal beds are given in the sections on the preceding page. The Crow Ridge section, which is given below, was measured by Dr. Barrell, and shows a thickness of 380 feet between the Madison limestones and the Cretaceous rocks.

Section of Carboniferous sedimentary strata (Quadrant formation) exposed on Crow Ridge northeast of Elkhorn.

	Thickness in feet.
6. Alternating pure and calcareous quartzites, just beneath the lowest Mesozoic quartzite	75
5. Quartzitic hornfels	20
4. Light-gray quartzite	7
3. Lime-silicate hornfels	20
2. Light-gray reef of lustrous quartzite	20
1. Banded strata of light-colored lime-silicate hornfels, ranging from nearly pure limestones to nearly pure quartzites, the base of the series	240
Total	382

MESOZOIC ROCKS.

Crow Ridge series.—Under this heading all the Mesozoic strata have been grouped, as, owing to the absence of well-defined lithologic units or of fossil remains, it has been impossible to differentiate the Juratrias or the groups composing the Cretaceous series. The only exposures of the formation which lie within the district are those of highly metamorphosed rocks. Their original character was unquestionably that of the impure limestones, shales, and sandstones which characterize the formations of this age in other parts of the State, and which may be seen well exposed a few miles east of Elkhorn. At present, however, the rocks consist of hornfels, adinole, and quartzite, and show very intense alteration. The rocks are exposed in the amphitheater south of Elkhorn Peak and in the upper gorge of Elkhorn Creek, where they dip steeply to the east, and the ledges may be seen running down the slopes.

The Crow Ridge series is best exposed on the southwest spur of Crow Peak, to which the name Crow Ridge is applied. The rocks consist near the andesite capping of light-cream, green, pink, and lavender hornfels and adinoles, alternating with steel-gray to pink quartzites. One bed of quartzite forms the narrow, even crest for one-half to three-fourths of a mile, the strike being N. 40° W. and the dip 20° E. A measured section was made of the rocks exposed on Crow Ridge, but the uppermost beds being capped by andesite the total thickness of the series is not known. The following section shows the thickness and character of the series.

Measured section of Mesozoic strata exposed on Crow Ridge, northeast of Elkhorn, Mont.

	Thickness in feet.
Andesitic lava flows, with tuffs and breccias at the bottom, lying upon an erosion surface of Mesozoic, terminate the series.	
Mixed sediments, lime and clay predominating:	
30. Lime-clay-silica banded hornfels with mottling due to segregations	180
29. Fine-grained dark shales with platy parting	260
Mixed hornstones and quartzites:	
28. Dark mottled lime-clay-silica hornfels	35
27. Dark granular sandstone consisting of a water-sorted arkose and what may be a devitrified volcanic glass sand	40
26. Light-colored lime-clay-silica mottled hornfels	60
25. Light-gray medium-grained sandstone	110
24. Dark limestone, rather impure	48
23. Calcareous quartzite	12
22. Light-colored lime-silica hornfels	40
21. Intrusive sheet of light-colored andesitic porphyry	3
20. Dark-blue hornstone	22
19. Thinly laminated quartzite	12
18. Pure, lustrous quartzite	15
17. Light-colored lime-silica hornfels	60
16. Somewhat mottled lime-silica hornfels	12
15. Coarsely granular quartzite	6
14. Light-colored lime-silica hornfels	45
13. Dark and conspicuously mottled hornfels	4
12. Medium-colored lime-silica mottled hornfels	8
11. Light-gray lime-silica hornfels	22

		Thickness in feet.
	Granular sandstones:	
10.	Light-gray, cross-bedded, granular sandstone, the grains consisting of what is probably a devitrified volcanic glass	50
9.	Similar to above, but bluish gray in color	37
	Limestone and hornfels:	
8.	Bluish-gray limestones with well-developed cleavage and many rust-colored hornfels bands	60
7.	Light-gray hornfels with many rust-colored bands	15
6.	Bluish-black limestones with well-developed cleavage	8
5.	Bluish hornfels, predominantly lime, with abundant white to rust-colored siliceous segregations	10
	Quartzite series:	
4.	Siliceous hornfels, somewhat banded, topographically prominent	150
3.	Coarsely granular quartzite, with some impurities	65
2.	Lime-silica hornfels, mottled with mineral segregations	20
1.	White, rather massive quartzite, topographically prominent	275
	Total	1,680

The petrographic nature of these altered rocks is fully described in the petrographic appendix to this report, and need not be further mentioned here.

CHAPTER V.

RELATIONS OF ROCK MASSES.

Under this head it is proposed to give a brief account of the relations of the rock masses to one another, including the probable manner of intrusion of the igneous rocks and their relative age. The rocks themselves have been described in preceding chapters; in this place a résumé is given of all the known facts concerning the dynamic geology of the region, with such conclusions as seem to be justified by the facts.

The surface distribution and areal extent of the different rock masses are shown on the geological map (Pl. XLV). The map does not, of course, give the known vertical relations of such masses, except in so far as they are expressed by the positions of the boundary lines in relation to the contours of the surface. The accompanying plates of cross sections (Pls. XLVIII and XLIX) represent vertical sections across the district along lines shown on the areal map, being designated by the same letters on lines and sections. The profile of each section is drawn from the contour lines of the topographic map, and the geologic boundaries correspond to those of the geological map. The size, shape, and relation of the rock masses shown on the sections, though based upon all the known facts, are largely ideal, and it is evident that this must be so, inasmuch as despite the marked ruggedness of the district the natural exposures embrace ordinarily less than 1,000 feet of vertical distance, and between Elkhorn Peak and the lowest point in the district the vertical distance is but 3,400 feet.

SEDIMENTARY FOUNDATION OF THE DISTRICT.

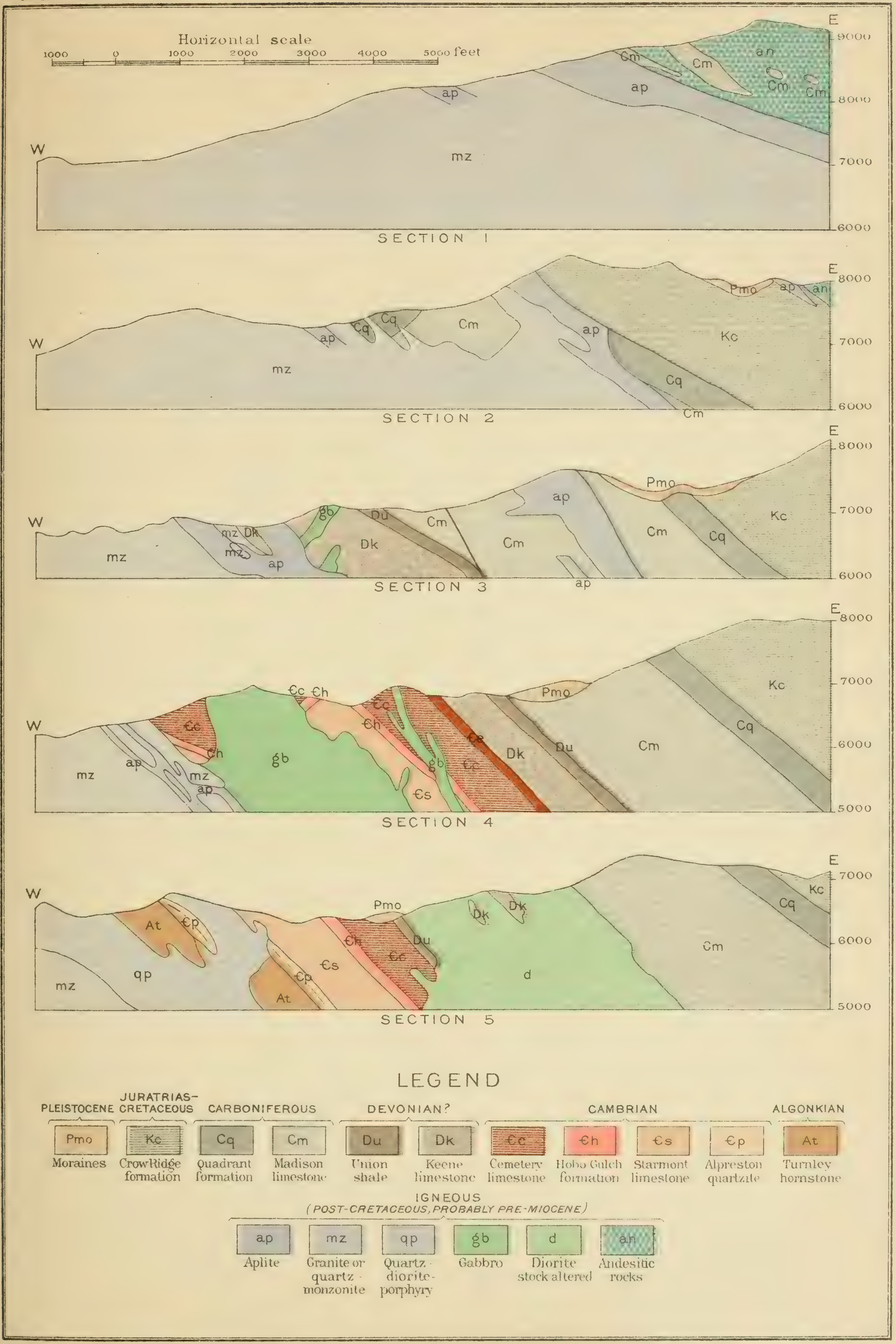
The sedimentary beds all lie at steep angles and have a prevailingly northward dip. The sinuosities of outcrop, as shown on the areal map, are largely due to topographic relief, since the strike is very uniform, being approximately north and south. The rocks are traceable into the beds forming the big fold east of Elkhorn Creek a few miles below the town, where the anticline is seen to be but one of the lesser folds of an extensive area in which the rocks form long anticlines with intervening synclines, and in which topographic relief and geological structure in general coincide very closely. The block of sediments at Elkhorn forms the eastern limb of an anticlinal fold, the western limb and crest of the fold having formerly existed in the area now occupied by the granite. The axis of this anticline pitched southward. Of the western limb of the fold nothing definite is known, though it may be conjectured to have been steep and likely to develop into a fault yielding readily to the disrupting force of igneous intrusions.

While the original structure of the sediments resulting from orogenic movements which preceded igneous intrusion was that of a simple arch, the folding of the rocks developed many lesser crumplings of the beds, and these creasings and crinkles, with accompanying slips and small faults, and crushing of the rocks of the big fold, were naturally most marked in the beds which formed the core of the arch. Such a minor fold is shown on the map 1,500 feet north of the shaft house of the Elkhorn mine by a marked bend in the outcrop; this little fold develops into a fault west of Alpreston Gulch. In the Cemetery limestone this fold sheared the rock and developed lines of fracture which were followed by the dike-like intrusions of gabbro, while the fault into which the fold developed determined the southern limit of the gabbro stock. Other minor crumplings occur, but the two just mentioned are the principal ones, because they influenced, if they did not determine, the position of the igneous intrusion with which the ore bodies are genetically connected.

GABBRO STOCK OF BLACK BUTTE.

The gabbro stock is believed to be the oldest igneous mass of the district. As shown by the areal distribution of the rock, it occurs in detached masses, with many small bosses and rounded intrusions breaking up through the sedimentary rocks that surround the main bodies, which are shown in the structure sections, Pls. XLVIII and XLIX, to be parts of one great body. The occurrence of the smaller intrusions, as well as arms of the larger masses, along northeast-southwest lines indicates that lines of fracture in the sedimentary rock were followed by the intrusion, though it is evident that the latter rocks were extensively shattered at the time of the intrusion. From these and other details of occurrence observed in the field, it is inferred that the gabbro underlies a large part of the region drained by Alpreston Creek and that the various exposed masses are all parts of one deep-seated mass, from which the stocks and pipes now seen rise upward like branches from the trunk of a tree.

The rocks adjacent to the exposed stocks show very great alteration—in fact, but little less than that of the included fragments seen in the rock. The strata about the Black Butte stock dip toward it from all sides, indicating a settling in of the crust upon the partially cooled and consequently contracted magma. This, however, is not a satisfactory explanation of the broken condition of the sediments south



CROSS SECTIONS OF THE ELKHORN DISTRICT
Showing hypothetical underground structure

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of Black Butte, where occur several small intrusions that are not shown on the geological map owing to their limited extent, nor of the conditions seen upon the west slope of Black Butte, where the gabbro holds so many fragments that in places more than one-fourth of the mass is composed of them. Such occurrences seem clearly to indicate the taking up of shattered or brecciated material resulting from the fracturing that opened a way for the intrusion.

Both the alteration of the sediments and the coarse grain of the gabbro indicate prolonged and intense heating, followed by slow cooling. It should be noted, however, that the granitic rocks caused a later reheating and alteration of this same area, and that the effects of thermal metamorphism now observable may be largely the result of such later action. It is certain that the gabbro is later in age than any of the sedimentary rocks, since it cut across the folded beds whose folding was later than the time of deposition of the Cretaceous beds of the district, a period certainly not earlier than Middle Cretaceous nor later than the Laramie.

The gabbro is known to be the oldest igneous rock because fragments of it torn off by the force of the later intrusions occur in the other igneous rocks. The western side of the Black Butte stock is sharply truncated by the granitic batholith, and it is impossible to tell what the former extent of the gabbro may have been. The chemical composition of the rock might suggest that it was a vent from which andesitic lavas were ejected, but this is not supported by the evidence. In fact, there is reason to believe that the entire mass was formerly covered by sediments, now largely worn away, and that no outlet to the surface ever existed. The intense alteration of adjacent rocks and the coarse grain of the gabbro certainly accord with this hypothesis and with the evidence that slow cooling of the mass took place.

DIORITE STOCK OF CEMETERY RIDGE.

In its relations to the sedimentary rocks the diorite stock southeast of the town differs markedly from the gabbro stock just noted. The extremely irregular contact seen on the map shows that the rock has broken up through the limestones and entirely replaced large masses of them. It is therefore remarkable to find isolated patches of Keene limestone lying upon the diorite and to observe a block of Elkhorn shale extending up the ridge far out over the diorite, yet maintaining its original position. Field observations show that this mass and the patches of Keene limestone are merely cappings over the diorite. It is apparent that they are parts of a cover of sediments now nearly removed by erosion. The presence of the Union shale within the diorite suggests that it was able to resist the corrosive action of the molten rock better than the limestone. Between the Elkhorn argillite on the west and the massive limestones forming the eastern wall of the intrusion at least 600 feet of limestone is missing, showing that the intrusion not only forced apart the strata, but caused the removal of great quantities of limestone. It is certain, from the observed facts, that the intrusion must have been a very quiet one, scarcely disturbing the overlying sediments; yet the removal of a great mass of the Madison limestone would indicate violent rupturing of the rocks. The replacement of so large an amount can be accounted for in various ways. (1) It may have been floated upward or been ejected from a volcanic vent. This suggestion is negatived by the positive evidence that the intrusion was covered by a sedimentary cap subsequently removed by erosion, and therefore there was no room for the floating of the blocks and no possibility of ejection. (2) The limestones, etc., that formerly occupied the place now held by the diorite may have been fractured by the force of the intrusion, and the blocks sunk down through the liquid magma into the reservoir from which the igneous matter came. (3) The limestone may have been assimilated and dissolved by the molten rock. The latter hypothesis is one for which absolute proof is necessary, as it is opposed to the observations made by scores of geologists the world over. Though the petrographic study of the rocks shows no proof of this, the facts observed here seem to indicate some such action—viz, the apparent corrosion or eating into the limestone by the diorite, the lack of disturbance of the strata, and, lastly, the very uneven, stringy, or smeary nature of the diorite itself, which, as is shown in the petrographic appendix, varies from shonkinite to quartz-diorite, and which in the field is seen to vary from place to place.

DIORITE-PORPHYRY LACCOLITH OF QUEEN GULCH.

The massive diorite-porphyry seen at the junction of Turnley, Queen, and Elkhorn gulches constitutes an intrusion which is laccolithic in character. The bottom of the mass rests upon altered sediments (Starmount hornfels) and andesitic rock, the contact plane dipping SW. at 42°. The exposure seen along the railroad loop shows that the intrusion domes up the andesites, the upper contact at this place dipping SW. at 25°. The andesitic cover has been largely removed by erosion, but enough is left to show clearly that the mass constitutes an inclined laccolith intrusive in andesitic rocks. Sections 6 and 8 of Pl. XLIX cross the laccolith at unfavorable places, so that the laccolithic structure is not well shown in them. The laccolith rock is clearly younger than the andesites, but as it does not come in contact with any of the other igneous rocks of the district no further statement as to its age can be made, though it might be inferred from the composition and mineralogic character that the rock formed a part of the general andesitic eruptions, and was therefore older than the quartz-diorite and the granitic rocks.

TURNLEY RIDGE QUARTZ-DIORITE-PORPHYRY STOCK.

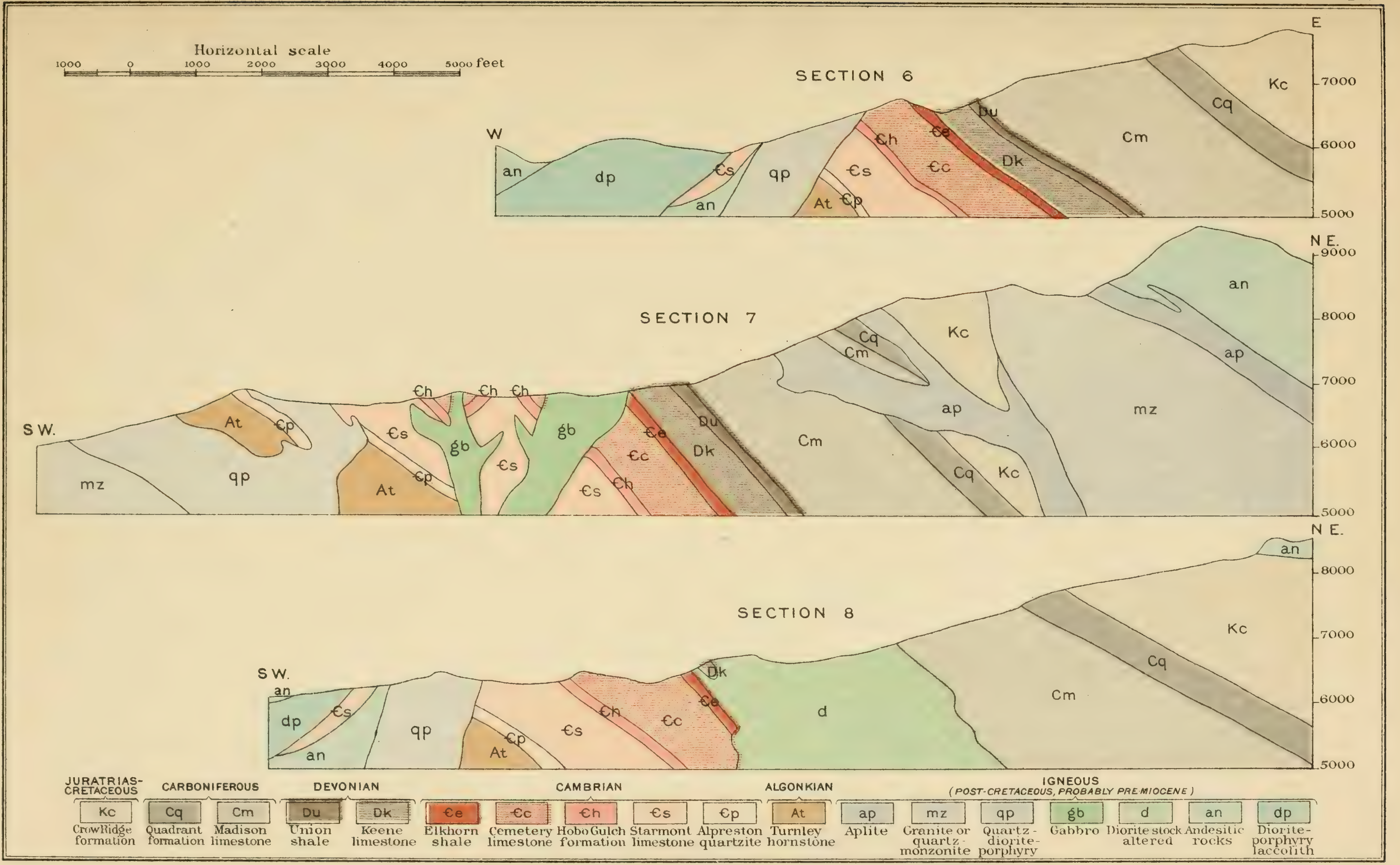
This rock forms a very irregular intrusion, breaking up through the oldest sedimentary strata and through the andesitic rocks at the junction of Queen and Elkhorn creeks. The mass is clearly intrusive, as is shown both by its field relations and by the contact chilling of the rock and the fragments of older formations which it carries. The intrusion itself is cut by the granite (quartz-monzonite), and the metamorphic effects due to the quartz-diorite-porphyry can not be satisfactorily distinguished owing to the great heat due to the later intrusion. The mass is deeply dissected by the gorge of Elkhorn Creek, and good exposures are common, though rock débris covers large parts of the area. The location and shape of the intrusion are believed to be due to the presence of Algonkian and Cambrian shales. These rocks, which are easily invaded by igneous magmas, owing to their weak resistance, are commonly the site for intrusive rocks in many districts in the State. It is true that these formations as now seen at Elkhorn are tough and resistant, but this character is the result of the metamorphism effected by the igneous magma itself or by later intrusions. It will be observed that the shape of the intrusion, as shown on the map, corresponds in a general way with the strike of the sedimentary rocks. The actual contact, however, is quite uneven, tongues of the porphyry invading the easily ruptured sediments and sending out wedge-shaped masses and sheets which split apart the strata. The southern end of the intrusive mass has a dike-like arm but a few feet wide which cuts across the sediments and is well exposed in Queen Gulch. To the north the mass is a mile wide and is bounded by a variety of rocks, into all of which, except the granite, it sends out intrusive arms. The granite is clearly later than this rock and cuts it. The map, Pl. XLV, and sections 5, 6, 7, and 8 of Pl. XLVIII show the relation of this mass to the adjacent rocks. It will be observed that the intrusion as drawn on the sections is assumed to widen out toward the surface. This is inferred from the fact that the rock has split apart the strata and sent out wedges into the rocks on every side, and this it could more readily do if the intrusion was somewhat funnel shaped, broadening at the top. The included mass of sediments shown in sections 5 and 7 of Pls. XLVIII and XLIX corresponds very closely in orientation to the masses lying to the north of the intrusion. These rocks, which are essentially quartzitic, probably extended northward and connected with a larger mass in the area now occupied by the granite. The writer does not believe that the evidence warrants the assumption that this large block of sediments has been torn loose and floated into its present position—a position so closely corresponding to the original one occupied by the sediments before the invasion of the porphyry.

The relative age of the rock is determined by very satisfactory evidence. At the contact with the andesite, where an apophysis of porphyry projects into the latter, the rock shows a distinct chill texture, visible to the eye and unmistakable when the rock is seen in thin section under the microscope. On the hill crest, 3,000 feet west of the town, the porphyry includes two masses of gabbro-diorite which, though too small to have produced any chilling of the porphyry, are themselves slightly metamorphosed. As these inclusions have a small slab of the Starmount hornfels attached to them, an association common in their original position, it seems clear that they are fragments broken loose from the main gabbro mass. The relations of the porphyry to the quartz-monzonite are also clear. The contact line is sharp and a careful search of the granite reveals occasional masses of quartz-porphyry but a few inches in diameter inclosed in the granite. It is therefore certain that the porphyry is an earlier intrusion and not merely a dike-like extension of the granite mass. The conclusion is reached, therefore, that the quartz-diorite-porphyry was the latest intrusion preceding the great welling forth of the granite.

ANDESITIC MASSES OF ELKHORN PEAK, QUEEN GULCH, AND ELKHORN GULCH.

Andesite.—Although great quantities of andesitic rocks exist in the district and form mountain masses for many miles about it, the rocks are almost entirely extravasated lavas. At Elkhorn Peak and at Turnley Gulch intrusive rocks occur, but the rocks do not constitute masses filling the conduits from which the breccias may be supposed to have come, but are later rocks cutting the breccias, though of the same general character and period of eruption. The source of most of these andesitic rocks must have been some point or points west of the district in the region now occupied by the Boulder batholith, the small size of the fragments composing the breccias and the easterly dip of the beds pointing to a source at least several miles westward. On the other hand, the extensive bodies of intrusive andesitic rocks carrying such enormous blocks of limestone as that now forming the marble cliff of Elkhorn Peak (XLVII, *B*) indicate a source of supply close at hand.

That the andesites formerly covered a large part if not all of the district seems probable from the occurrence of these rocks in Queen Gulch, at a low elevation, and in the gorge of Elkhorn Creek below the mouth of Queen Creek. The physiography of the region shows that it has been extensively faulted since the granite batholith was formed, but despite this the evidence seems clear that the andesitic rocks were thrown out by volcanic eruptions of great magnitude, and fell upon and covered a region consisting of highly folded sediments carved into a country nearly as rugged as that seen to-day. There seems no alternative but to accept the conclusion that these rocks cov-



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Showing hypothetical underground structure

ered the district to a considerable depth, the surface sloping rapidly toward the southeast. Despite the enduring character of the rock and the fact that the highest peaks are now formed of it largely because of this character, it is true that it wastes and is removed by stream and frost very rapidly, and enormous masses of it must have been removed and carried down into the valley of the Jefferson River during the long period that has intervened since the formation of the rocks.

Marble cliffs.—The andesitic rocks of Elkhorn Peak consist in part of indurated metamorphosed fragmental rocks—volcanic breccias and tuffs—forming its summit and the crest westward, and of underlying massive intrusive rocks, which sometimes occur as sheets between the altered breccias and constitute the great mass of Elkhorn Peak. The latter rocks have apparently been intruded during the activity of the andesite volcano, being injected between the sedimentary platform and the overlying fragmental material making the former volcanic cone. A measure of the magnitude of the intrusion just mentioned and of its force is afforded by the inclusions of altered limestone found within it. These inclusions are clearly blocks torn off from the underlying Madison limestone and borne into their present position by the force of the ascending magma. The largest block is well exposed on the western flank of Elkhorn Peak and in the white cliffs which are so conspicuous a feature of the peak, and look like a bank of snow when seen from the south. These cliffs are shown in Pl. XLVII, *B*, which has been made from a photograph taken on the shores of a lakelet that fills a hollow in the amphitheater bottom. Beneath the white marble cliffs the dark andesite is seen, with a second or lower stratum of white marble beneath it. The view shows the dark-colored andesitic rocks projecting above the snow bank that overlies the marble cliffs. The higher slopes seen on the right-hand side of the view are also andesite, but the line of cliffs beneath them consists of hornstones belonging to the Mesozoic or Crow Ridge series, with a tongue of aplitic granite beneath them. The rock composing the white cliffs is a very coarsely granular and glistening marble whose individual grains are oftentimes an inch across. The mass is 125 feet or more thick in the cliff, and may be traced across the gently sloping shoulder of Elkhorn Peak for a distance of 3,000 feet. The lower marble mass seen in the view is in some places 50 feet thick, and is also traceable across the north side of the peak for a distance of not less than 2,000 feet, though it is in part concealed by débris, and its northward extension is inferred from the presence of occasional blocks of limestone and from exposures afforded by several prospect pits. This lower mass of marble is cut by stringers and dikelets of andesite. Its eastern end is abruptly truncated by the andesite, and westward it gradually wedges out, as shown on the map. The rock, though in the main a pure marble, contains two bands of white hornstone, one 3 feet and the other 3 inches in thickness. These hornstones are clearly an alteration product of interbedded layers of impure limestone, and therefore show the original stratification planes of the rock. They dip NE. at 18°. To the southwest the lower block of marble rests upon aplitic granite, which has been intruded between it and the andesite, the latter rock elsewhere underlying it. The upper and larger block of marble also shows by a band of impure limestone that the dip of the strata is slightly greater than the dip of the underlying mass. It appears probable that these two blocks were formerly united and have been wedged apart by the intrusion of andesite, the relative position of the blocks indicating that the wedge entered from the west. The isolation of these blocks at an altitude of several thousand feet above the Madison limestone and so near the Mesozoic beds shown in the plate indicates either that very profound faulting has occurred, or that these blocks have been torn from some deep-seated mass and floated into their present position in the liquid andesite inclusion. Direct upward movement is improbable in view of the wedging apart of the blocks from the west. The more reasonable hypothesis—and one supported by the occurrence of many smaller included blocks of marble seen in the cliffs to the east—is that a great flood of andesitic magma welled up from some vent to the westward, lifted the overlying breccias, and intruded itself between them and the Mesozoic shales.

In summary, the facts already presented show that the andesites rest upon sedimentary rocks of greatly varying age and that the contact occurs at widely different elevations. It is inferred from this that the breccias and lava flows composed of these rocks covered a very rugged area of sedimentary strata. The breccias show a rude bedding dipping eastward on Crow and Elkhorn peaks and southward in the mountain mass southwest of Elkhorn. These relations indicate that the source of the material lay somewhere to the west of the Elkhorn district, and from the character of the beds there seems reason to believe that the masses now seen are the residual parts of a great volcanic pile whose center lay some miles to the west of Elkhorn. Direct evidence of this has been removed as a result of the granite intrusion, with later uplift by faulting and subsequent erosion, but parts of the western slope of the former andesitic volcanic cone may be well seen west of Boulder Valley.

GRANITIC BATHOLITH.

As noted in the introductory chapter, the Elkhorn district includes the border of a great granite area extending for many miles to the west of Elkhorn, and reaching from the vicinity of Helena to the Highland Mountains south of Butte. This great mass of granite is all one connected mass and has been named the "Boulder batholith."

On the reconnaissance map that shows the relations of the Butte district to the surrounding region this batholith has been outlined and its relations have been studied. At a number of points throughout the granite region this rock is covered by andesitic rocks which were at first thought to be more recent than the granite, lying as they do upon it. Isolated masses occur at scattered localities, and in each case the relation seems to be the same. Notwithstanding the altered character of the andesites, which quite clearly showed the intrusion and metamorphism of the fragmental forms, no positive evidence was developed in the central part of the area of a more recent age of the granite. Later studies, however, at Elkhorn, at Pipestone Hot Springs, and at a point midway between these two localities, showed conclusively that the andesite is older than the granite, as fragments of it are included in the granite mass near its borders. Abundant evidence that the aplite is later than the andesitic rocks was found at Elkhorn. The specimen figured in Pl. LXII, *B*, shows this relation, as a minute stringer of aplite is seen penetrating the fractured andesite. These facts, together with the metamorphosed condition of the breccias seen upon the granite, show that the andesites are in part, at least, the remnants of a former cover to the granite batholith, the latter having broken up through an extensive area of andesitic rocks, the heat of the intrusion producing a metamorphism of these rocks, as it has of all the others adjacent to it. The nature and manner of intrusion of such enormous masses of granite are as yet imperfectly understood, but the present district offers exceedingly favorable conditions for a study of such phenomena. As, however, the problem is a large one and must be studied in its entirety, it is not within the province of this report to deal with it, except in such features as may come within the Elkhorn district.

Within the region herein described the granitic rocks are clearly of later origin than any other rocks. They are intrusive in the other igneous rocks and carry fragments of the latter. They abut against the truncated ends of the sedimentaries, and have undoubtedly displaced large amounts of both sedimentary and igneous rocks lying to the west of the present limits of those formations.

The granitic rocks of the batholith are extensively fissured. These fissures are grouped, and are much more prominent in some areas than in others, closely sheeted rocks occurring near areas showing no sheeting. The very striking bowlders and groups of monoliths that distinguish the granite area are due to the presence of these fissures. The fissures belong to two well-marked systems: (1) A system of vertical joints is most common, and produces a true sheet of the rock; the planes are vertical or approximately vertical, and are observable everywhere throughout the batholith, though the closeness of the sheeting planes varies greatly from place to place. Close spacing occurs in local areas, and may result in a platy structure of the granite; more commonly the fissures are farther apart and do not show except on weathered surfaces. The direction of the vertical fissures varies greatly in different parts of the batholith. In the Elkhorn area their strike varies widely, as is shown by the strike and dip marks on the geological map, Pl. XLV. In general, however, there is a tendency for the sheet to approximate parallelism with the contact line between the granite and the other rocks. (2) Diagonal fissures are always present, though often obscured by the more prominent vertical system. Their recognition is dependent upon their development by weathering. These diagonal fissures dip in opposite directions, the angle between them being 90°, though their strike is the same. The result is the intersection of the granite into rudely rhombic forms. Becker[1] has shown that such fissures are fault planes; that they never gape, but are mere cracks; that they are not partings or true joints; that they show movement by occasional slickenside faces and by measurable displacements usually of less than an inch for each fissure. The aggregate of such minute displacements he has estimated to be several thousand feet for the Sierras.

The batholith rock is remarkably free from inclusions of other rocks, even where it has broken irregularly through them. Only two small limestone inclusions have been seen in the granite at Elkhorn, and these are shown on the geological map. The first is a block of marble about 65 feet wide and 100 feet long; the second a mass of garnetiferous lime-silicate rock some 200 feet across.

The peculiarities of rock metamorphism observed on Crow Ridge give ground for the belief that the granite batholith extends under the sedimentary area of the district, the contact dipping to the east, but no direct evidence has been obtained to show that it does so here, as it does at other places about the borders of the batholith.

The andesites rest upon an eroded surface of sedimentary rocks as irregular as that seen in the district to-day, and it is therefore evident that the granite, where it is exposed near such contacts, was not covered by sedimentary rocks, but must have come against andesites. Moreover, in the central parts of the batholith remnants of an andesitic cover still exist, and the granite must have either penetrated between the andesites and the base upon which they rested or removed the basal rocks, whatever they were. A consideration of these relations and of the profiles shown in the cross sections shows that the batholith cover was never very great and probably consisted of 1,000 feet or less of andesitic rocks.

The formation of the granite batholith obliterated all evidences of the former character of the western part of the Elkhorn district. Since the batholith was formed there has been no further igneous activity within the borders of the Elkhorn district. To the west sporadic outbursts of rhyolitic magmas occurred at a somewhat later period, but as they often rest directly upon the granite they show that a long period of erosion intervened after the formation of the batholith, a period sufficient to permit the carrying away of the andesitic cover over a part, at least, of the area. In the Elkhorn district the work of erosive agencies has materially modified the surfaces, but the relative elevation of the peaks is probably the result of faulting in which north-south faults depressed the Elkhorn and Crow Peak area relatively to the Boulder Valley. Within the immediate district itself there is, however, little evidence of faulting. The sheeting or distorting of the granite has already been mentioned, but inasmuch as deformation by shear would scarcely show in the altered rocks if it were distributed over a considerable area, any slips or faults which might be individually insignificant would be rather large in the aggregate. Two cases of faulting were observed in the surface rocks. The first is a fault plane dipping east at an angle of 40° and cutting two small diorite dikes which permit a measurement of the displacement, which proves to be but 3 feet in the southern part. This is seen in the railroad cut 1,800 feet south of the station. A second instance is seen in the southern part of the district, where three faults, whose dip is N. 10° E. and whose angle of dip is 50°, traverse a block of Starmount hornfels and produce an aggregate throw of about 6 feet. These faults, like those seen in the underground workings, are small and seem referable to the granite intrusion.

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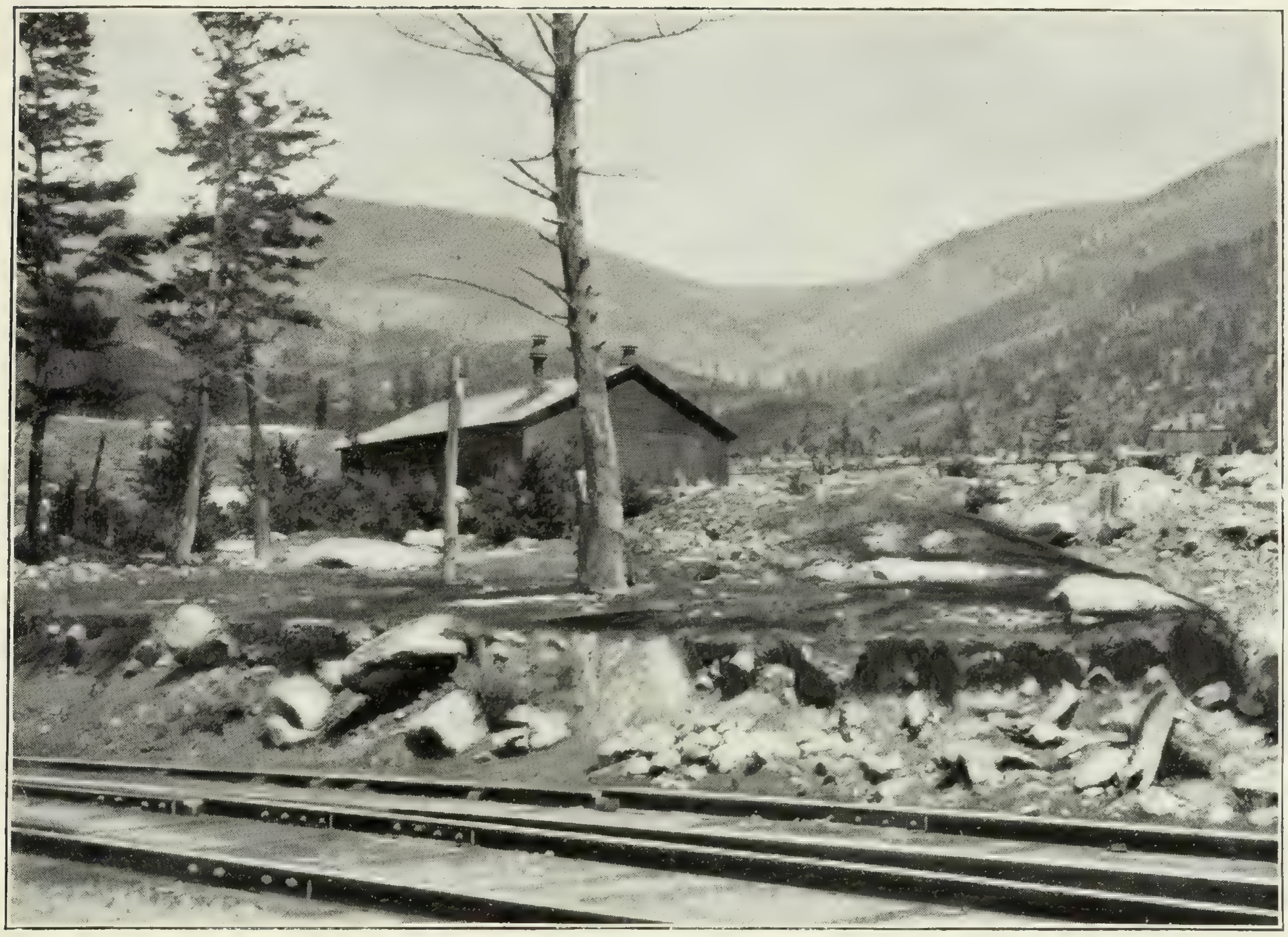
[1] Structure of a portion of the Sierra Nevada of California: Bull. Geol. Soc. Am., Vol. II, p. 50.

Concerning the later history of the region, it can only be said that it has suffered continued and prolonged degradation from ordinary atmospheric agencies since Miocene times, the only marked episode in its long period of erosion being that of local glaciation. The tilting which ponded the rivers of the State and filled the larger valleys with lacustrine débris has left no record of its action within this area, and, indeed, does not appear to have affected the general relations of the rocks. The amount of erosion that has taken place can not be reliably estimated. It is, however, evident that several thousand feet have been removed since the batholith was intruded, for the andesites of Elkhorn Peak were at least 1,000 feet thick on the western flank of the mountain, and over this area these rocks have been removed and the granite itself has been trenched to a depth of 3,000 feet or more.

GLACIATION.

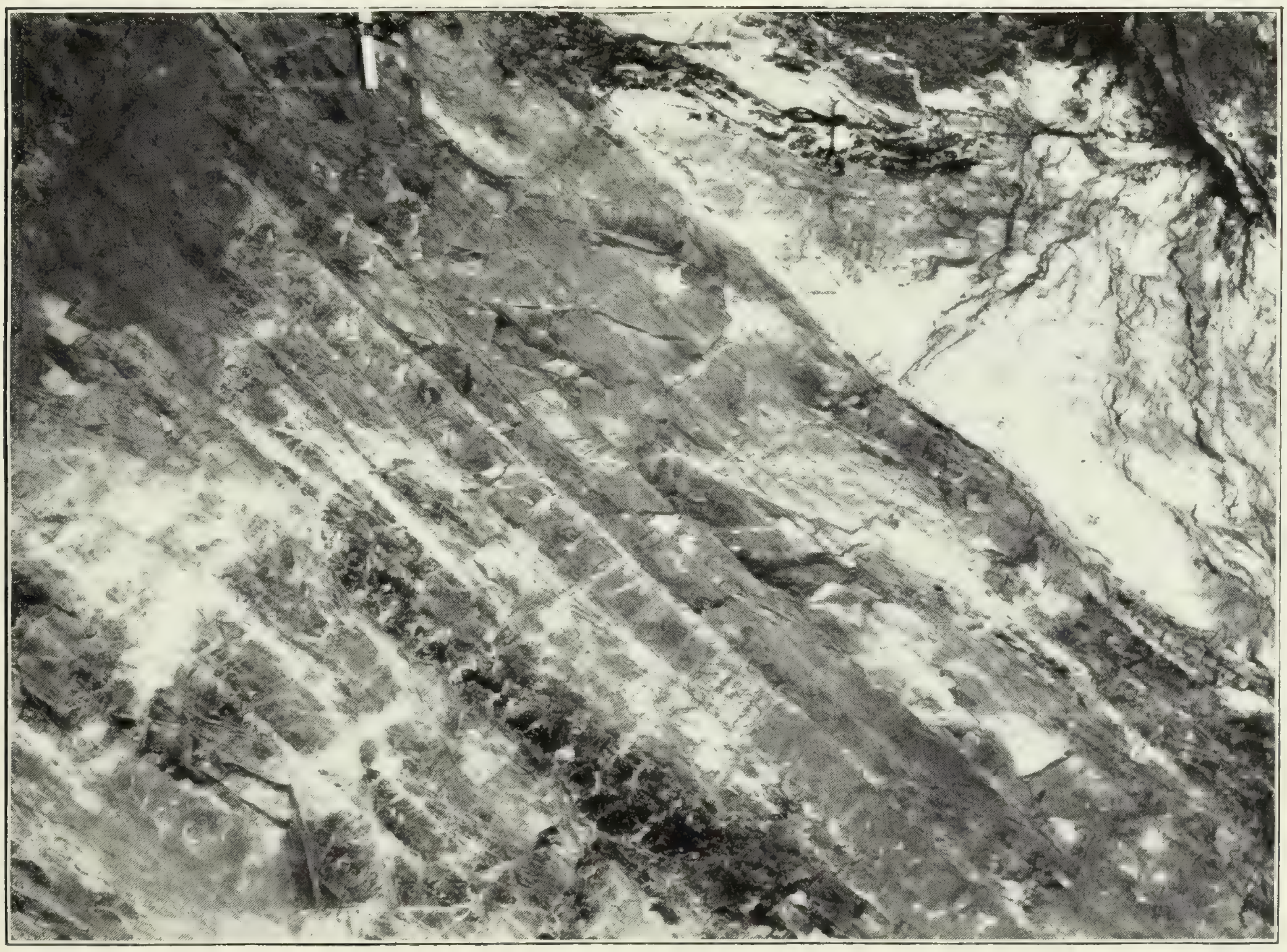
In the Elkhorn district the effects of glacial action are seen at several places in conspicuous morainal heapings and accumulations of bowlders. The most prominent moraine extends entirely across the valley of Elkhorn Creek above the town. This is well shown in Pl. L, *A*. There is a widespread distribution of bowlders in the mountain gorges that indent the side of Elkhorn Peak, but the district was never covered by a general ice sheet, the glaciation being purely local and of the alpine type. The snows of each winter accumulate to considerable depths in the amphitheater of Elkhorn Peak and exist as snow banks late into the summer, and through the Glacial epoch these amphitheaters were undoubtedly filled to a depth of 1,000 feet or more. This snow must have formed small glaciers during the early Pleistocene period, which pushed down the principal gulches, the largest glacier coming down Elkhorn Creek a couple of miles and depositing the bowlder material on which the town is built. Pre-Glacial erosion undoubtedly furnished an abundance of loose material, which, together with the blocks loosened by frost from the amphitheater cliffs, were borne on the surface of the ice or carried in its grasp to form the well-marked moraines now seen. The amphitheater walls show no evidence of ice erosion other than the removal of the débris and the general clearing out of the amphitheater. Rounded and ice-worn ledges of andesite are seen near the divide east of Elkhorn Peak. The amphitheater floors, however, show no rounded bosses, but are littered by bowlders which conceal the underlying rock. The water-filled glacial hollow, seen in XLVII *B*, and two similar depressions lying a half mile to the northeast are possibly rock basins, though the accumulation of débris prevents positive proof.

The glacier which flowed down Elkhorn Peak was formed by the confluence of two sheets, one coming from the marble cliff amphitheater south of Elkhorn Peak, the other from the amphitheater between Elkhorn and Crow peaks. The two glaciers united below Icy Lakelet, the pool shown on the map and in Pl. XLVII, *B*. The western glacier was the larger and crowded the lesser one toward the east, and in its retreat left great bowlders of granite scattered over the andesite slopes and upon the metamorphosed Mesozoic shales. The confluent ice sheet flowed down the valley to a point opposite the mouth of Alpreston Gulch, reaching an elevation of 6,300 feet. At a later period its front was about one-half mile above the town of Elkhorn, at which point the ice must have maintained a nearly constant position for a considerable length of time, as the terminal moraine at this point is unusually large for so small a glacier, being several hundred feet high and extending clear across the valley. As seen from the town, it completely dams this valley, as is well shown in the photograph taken from near the railroad station, Pl. L, *A*. This moraine shows a step-like profile, and consists of granite bowlders up to 10 feet in diameter, with smaller masses of andesite and hornstone, the whole forming mammillary hummocks with intervening kettle holes. This terminal moraine passes northward into a well-defined lateral moraine lying high up on the slopes west of the valley, while a much smaller lateral moraine is seen low down on the opposite eastern slopes. In the



A. BOWLDER MORAINE AT ELKHORN.

In the middle distance is seen a well-marked terminal moraine, extending across and completely damming the valley. Saddle between Elkhorn Peak (on left) and Crow Peak (on right) seen in background.



B BEDDING PLANE BETWEEN SLATE AND DOLOMITE, 2,200-FOOT LEVEL, ELKHORN MINE.

The illustration shows difference in fracture and well-marked bedding of the slate.

granite area at the head of Turnley Creek the moraine is less conspicuous, as the glacial bowlders are all of granite and aplite, and rest upon a granite surface, where they closely resemble the ordinary bowlders of disintegration common to the granite area. There is a strong contrast in the character of the glaciated and unglaciated areas. The valleys which have not been glaciated show steep sides and rounded bottoms, with firm soil and no swamps, while the glaciated parts of the same valley are paved with huge bowlders and show a scanty dark soil covered with rank vegetation and occasional swampy areas. The geological map, Pl. XLV, shows the extent of the ice-covered areas, the well-marked moraines being indicated by a darker tint than that marking the general extent of the bowlder heapings. It is evident that glaciation did not materially affect the topography of the region, though many of the picturesque aspects of the present scenery are due to its erosive action.

CHAPTER VI.

GENERAL EFFECTS OF THERMAL METAMORPHISM OF THE ROCKS OF THE DISTRICT.

The following account of the more prominent features of the thermal or contact metamorphism of the sedimentary rocks by the igneous intrusives presents only the more salient results of this action.

Both the sedimentary rocks and the later igneous rocks have been metamorphosed by the great bodies of molten magma intruded in them. This change, often called local or contact metamorphism, is herein designated hydrothermal metamorphism, because it is due to the heat and vapors of molten intrusion. Since it is caused by the igneous masses, the alteration is naturally greatest near them, and is less and less away from their borders. The changes due to thermal metamorphism differ very markedly from the results of ordinary rock disintegration, or rock alteration, and are also different from those changes which are due to metasomatosis. Thermal metamorphism embraces those changes produced in a rock mass by the influence of high temperature due to the intrusion of an igneous magma. These changes are of two kinds; first, physical; second, mineralogical. The physical changes are very marked. In limestones the alteration consists of a bleaching or whitening of the rock and its conversion into coarsely crystalline marble. In impure limestones the alteration results in marked mineralogical changes which give the rock an entirely different color, character, and appearance and make it usually coarser grained and harder than the original rock. The sandstones are altered to compact, almost flinty quartzites. The clay shales and the associated rocks, which consist largely of clay, together with calcareous or siliceous matter, are intensely altered and most commonly are found to form very dense, hard rocks of extremely compact texture which break with a conchoidal fracture and which, because of this compactness and smooth fracture, are often called hornstones. These hornstones have lost almost all trace of the original plane of bedding. They break in either dicy or rhomboidal bits, and the original stratification can be determined only by faint color bands. Very often, however, even this criterion is difficult to distinguish unless weathering develops a surface on which the original bedding plane is indicated by slight ridging. In none of the altered rocks at Elkhorn is a true slaty cleavage developed, either by thermal metamorphism or by other changes. In the less altered rocks a lamination which approaches a slaty structure in general appearance may still be observed, but in this case, as, for instance, that of the hanging-wall rock of the Elkhorn lode, the apparent slaty cleavage coincides with the original bedding of the rock or is due to slipping along bedding planes.

The mineralogical changes are those due to a rearrangement of the material composing the rock, a change in which new chemical combinations are effected and new minerals formed. In pure calcareous rocks the limestone is simply recrystallized and forms a marble whose coarseness of crystallization is in a way a measure of the intensity and duration of the heating of the rock.

The argillaceous rocks commonly contain silica, and recrystallize as aluminum silicates. The pure siliceous rocks recrystallize as quartzites. It is apparent that without the addition of material from outside, as, for example, by pneumatolytic action, the pure silica and pure lime rocks do not change in mineralogic composition. Where, however, the rocks are mixtures, as is so commonly the case in sedimentary strata, they are strikingly altered. The siliceous calcareous shales form coarse and patchy aggregates of lime and magnesian silicates. Diopside and garnet (the lime-aluminum garnet, grossularite) are very common, and, if iron is present, epidote occurs in abundance.

Arenaceous rocks.—Sandstones are but little affected by thermal metamorphism unless they contain impurities. A pure quartz sandstone will recrystallize as a quartzite if the temperature be sufficiently high, and this has happened at many places in the district. As a rule, however, the alteration consists in a hardening of the sandstone and not an entire recrystallization. If the original rock was impure—and impure sandstones are especially common in the Mesozoic strata composing the long spur of Crow Peak lying to the northeast of Elkhorn—the resulting product may not have any resemblance to the quartzite, but may consist of garnet, mica, etc.

Argillaceous rocks.—The shales are commonly baked or altered to a dense, flinty product known as hornstone, which breaks in angular chippy fragments and commonly has a well-developed cubical fracture, often breaking into cubes. It is usually dark colored, has a very homogeneous and very finely granular texture, which is sometimes sugary. These pass into those forms in which the metamorphism has been greater and the rocks are light colored, white, pale green, lavender, or pink, and have the texture and appearance of a fracture surface of porcelain. A perfectly pure argillaceous rock would form micaceous schists, but most of the shales contain impurities which determine their alteration to compact, fine-textured rocks consisting of various alteration minerals. In this district the spotty slates and flecked rocks seen in similarly metamorphosed areas elsewhere were not observed. Such spots are due sometimes to carbonaceous matter where the rocks are slightly metamorphosed, or in more altered forms to areas free from mica. At Elkhorn extreme metamorphism has resulted in the formation of extensive masses of compact-textured rock which are best grouped as hornstone.

Calcareous rocks.—The most striking effects of hydrothermal metamorphism are produced in the impure argillaceous limestones or calcareous shales. In these rocks the carbonic acid is completely eliminated and the whole is converted into a lime-silicate rock. As the alternating strata frequently consist of very different original material, the resulting rock varies greatly in appearance and may consist of aggregates, often coarse, but commonly fine grained to compact, of lime-rich silicates, with quartz, biotite, etc.

Fumarolic alteration.—The presence of tourmaline and axinite shows that there has been fumarolic action as a result of the vapors of the cooling igneous rocks. That such vapors are developed in large quantities by magmas is well known from observations on active volcanoes as well as abundant evidence about which there can be no doubt. Such vapors would naturally penetrate along fissures or porous strata and produce marked alteration.

The impregnated bed of garnetiferous hornstone which constitutes the ore body of the Dolcoath mine may have originated, as suggested by Dr. Barrell, from the shrinkage induced in a stratum of impure limestone contained between beds of pure limestones which have suffered little change in mass or volume. In the metamorphism of the impure stratum the carbonic acid is driven off and the rock loses upward of 30 per cent of its weight and 50 per cent of its volume, and, being steeply tilted before metamorphism, the result would be a porous layer whose formation may be likened to that of terra cotta or brick from clay. Such a porous layer would afford ready passage for fumarolic vapors or mineralizing gases. The ore stratum is evidently an altered limestone bed. It is 15 to 18 inches thick and dips E. at 55°. The ore occurs as silvery spots from 1 to 25 mm. across, and is often associated with calcite scattered through the rock. It consists of telluride and sulphide of bismuth carrying gold. The ore is apparently confined to this narrow stratum because its porosity is greater than that of the adjacent and confining limestone beds. The rock holding the ore consists of nearly equal parts of diopside and grossularite with calcite, as noted in the appendix. The ore occurs with diopside as well as with calcite. The latter is evidently a product of later infiltrating solutions, as it forms veinlets and fills the cavities lined with crystals of garnet, diopside, etc., with poikilitic calcite crystals.

CHAPTER VII.

MINERALS OF THE ORE DEPOSITS OF THE DISTRICT.

The ore bodies of the Elkhorn district contain but few mineral species, and most of them are of common occurrence in ore deposits elsewhere. The oxidized portions of the Elkhorn lode have, however, yielded native silver in crystalline aggregates of extreme beauty, the specimens being equaled in America only by those of the Batopilas mine in Mexico, while the calamine, found abundantly in the upper levels of the Elkhorn mine, is perhaps the finest crystalline material yet found in this country.

The minerals composing the contact-metamorphic rocks, which constitute the gangue of some of the ores in the lesser deposits of the district, are sometimes finely crystallized. This is particularly true of axinite, but garnet, epidote, and other minerals also occur in crystalline masses.

ORE MINERALS.

The ore minerals proper include the metallic sulphides, galena, bournonite, tetrahedrite, pyrite, and blende, with indeterminable rich silver sulphides. The decomposition or oxidized products of these sulphides, found in the upper parts of the deposits, include native silver, cerussite, calamine, a little minium, malachite, horn silver, linarite, aurichalcite, and descloizite. Accompanying these the gangue minerals quartz, dolomite, and calcite occur, together with fragments of country rock, garnet, and pyroxene.

Galena (*sulphide of lead*).—Argentiferous galena forms ore bodies in the Elkhorn, Queen, and C. and D. mines, as well as in a number of prospects. It occurs massive, is usually coarsely crystalline, and is commonly associated with blende, and sometimes with pyrite. It is frequently somewhat shattered, and crumbles readily on being struck with a hammer. No well-formed crystals were seen, nor any material of undoubted secondary origin. It occurs in bunches or pockets with the pyritic ores in the C. and D. mine, and forms great masses in the foot-wall limestone of the Elkhorn mine, which, upon extraction, left large caverns.

Bournonite.—This antimonial sulphide of copper and lead occurs sparingly in the quartzose ores of the Elkhorn mine. No well-crystallized specimens were seen, the mineral occurring as grains scattered through the quartz and somewhat resembling the more common tetrahedrite.

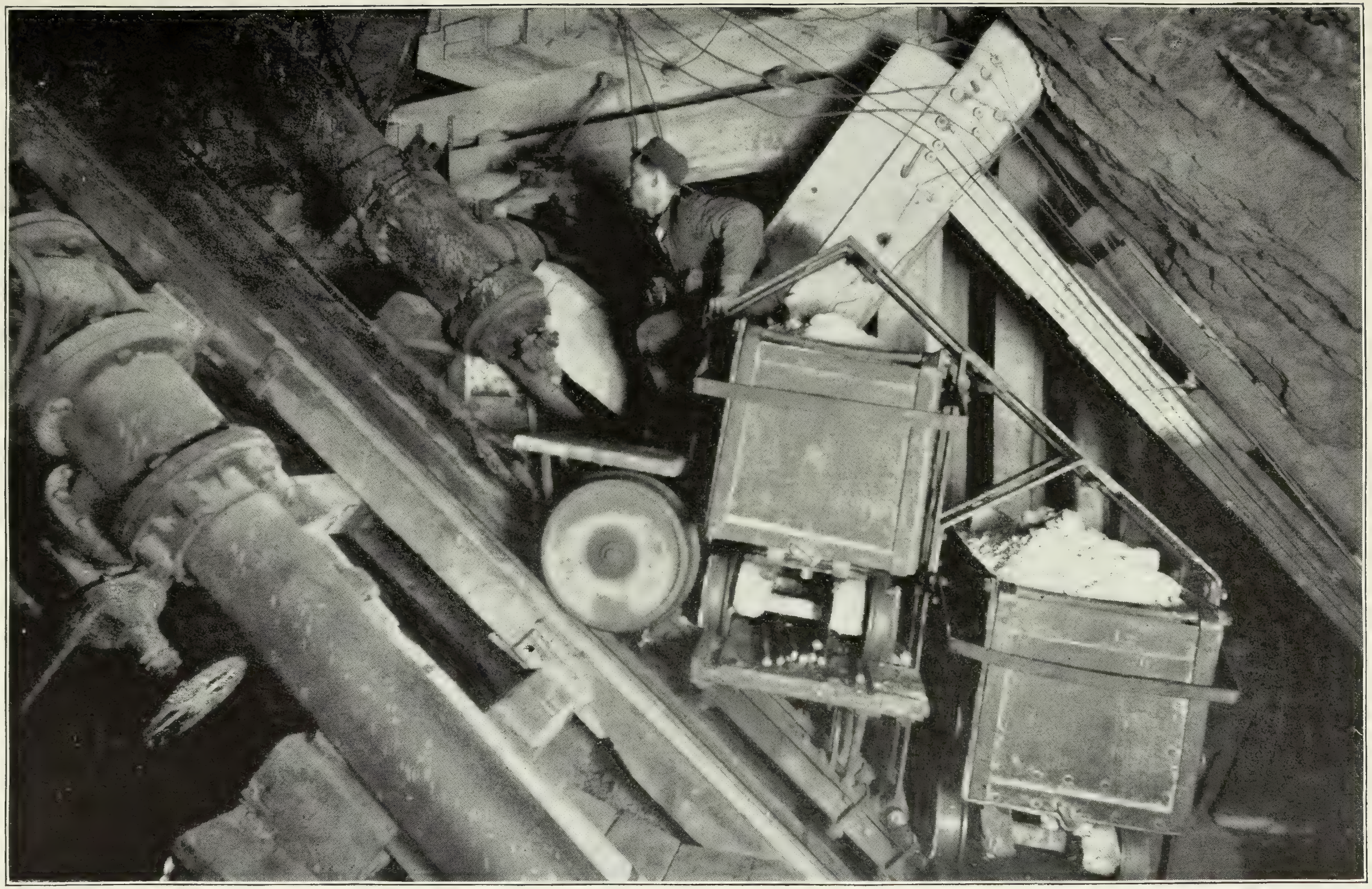
Tetrahedrite (*gray copper ore, antimonial sulphide of copper*).—This mineral occurs abundantly in the Elkhorn mine, where it is highly argentiferous, and probably also contains lead. It is always coarsely crystalline and massive, and occurs in grains and masses in the quartzose ore, where it is associated with pale-brown blende. It is rarely found in the foot-wall bodies, and is then also associated with quartz. It is probably the parent mineral of the native silver and silver-rich oxidized quartzose ores of the mine.

Pyrite (*iron sulphide*).—This is of common occurrence, not only in the Elkhorn mine, but in all the prospects of the district, and is also found in grains scattered through the igneous rocks, particularly the gabbro and the diorite-porphyry. In these rocks it is in part of primary origin, but mainly secondary formation, and was undoubtedly derived from the augite and other ferromagnesian minerals by the action of mineralizing solutions or vapors in the ore bodies. It is usually massive, very light colored, and forms the bulk of the ore in several mines. In the Elkhorn mine, though abundant, it does not form a large part of the ore, and is usually massive. In the drusy cavities in the massive pyritic ore well-crystallized specimens have been found which show the usual well-formed pentagonal dodecahedron; more rarely it occurs in cubical form. Assays made of the pyritous ore show it to contain silver, but as the massive material usually contains admixed particles of galena it is probable that the silver comes from them.

Tetradymite (*sulphide and telluride of bismuth*).—This mineral occurs in grains up to one-eighth of an inch across in the garnetiferous rock of the Dolcoath mine. It is somewhat altered in the oxidized material for a few feet below the surface, and then shows masses of free gold having the usual rusty or bronzy tint of gold derived from a telluride. The fresh mineral is brightly metallic, with the usual silvery luster, and shows a distinct foliation. Tests made in the chemical laboratory show it to be a mixture of bismuth telluride and bismuth sulphide. In altering, the mineral loses its laminated character and the folia become fibrous. It occurs in minute grains disseminated through the garnet, and in larger grains associated with calcite in the massive garnet of this mine. The origin of the ore deposit and the genesis of the mineral is discussed in an account of the Dolcoath mine.

Bismuthite (*sulphide of bismuth*).—This mineral occurs intimately associated with, and in the specimen is indistinguishable from, tetradymite. It is found only in the Dolcoath mine, and its presence was determined by chemical analysis by Dr. H. N. Stokes in the Survey laboratory.

Blende (*sphalerite, zinc sulphide*).—This mineral occurs associated



INCLINE SHAFT OF THE ELKHORN MINE.

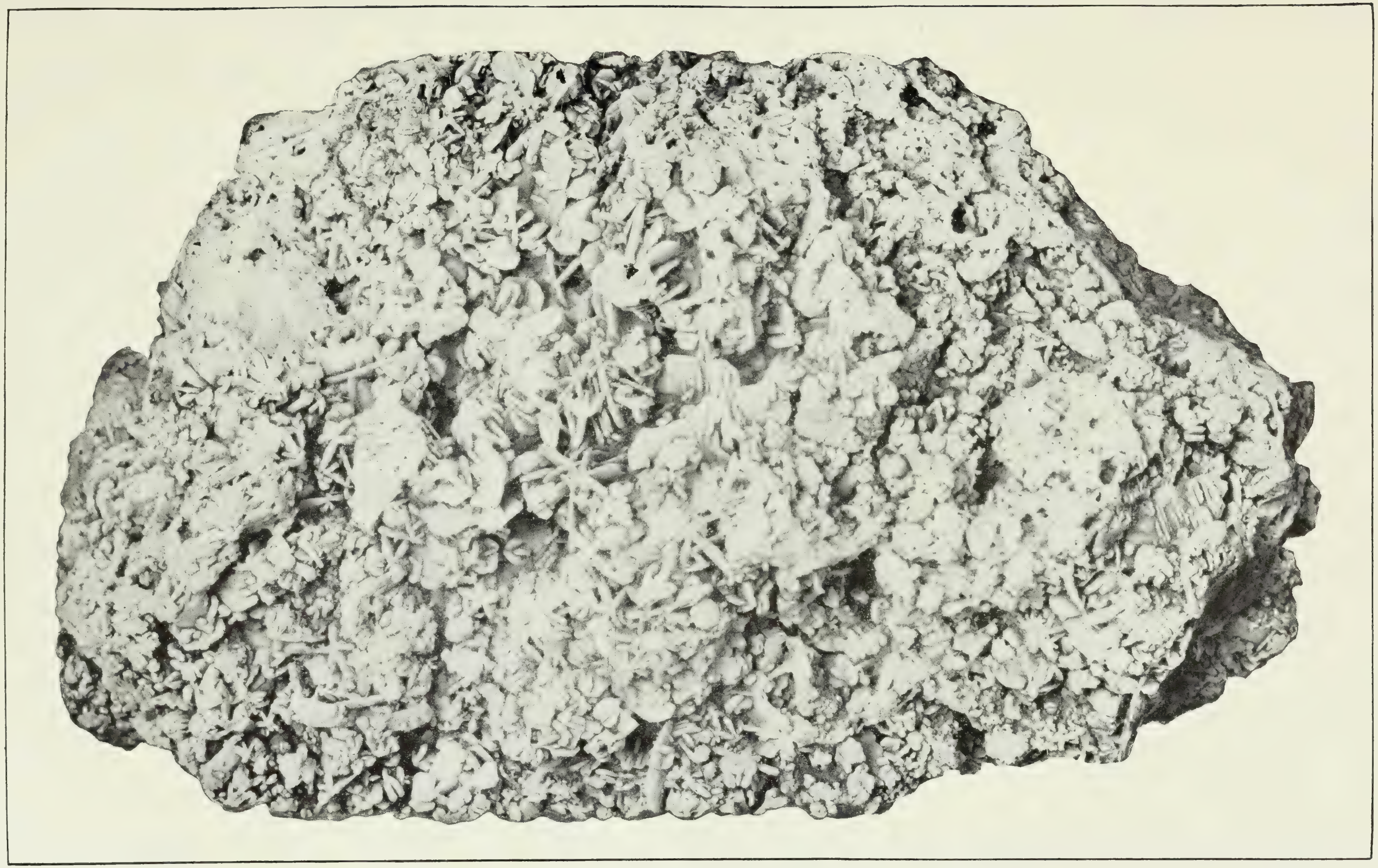
Shows method of timbering station, arrangement of pump pipes, and method of hoisting ore on two platform skips; slate "hanging wall" is seen above the skip.

PLATE LII.

PLATE LII.

CERUSSITE.

This plate shows a photograph of a specimen of cerussite in which the rosettes consist of plates that are relatively small and are coated by a film of quartz, so that this specimen is not so fragile as those commonly seen. The cerussite is in part, at least, formed upon nucleal fragments of oxidized quartz ore, but cerussite makes up the greater portion of the specimen. The reversed side shows a coating of minute calamine needles upon the quartz that encrusts the cerussite. The crystals are about one-fifth the size of some that were seen. Illustration is one-half natural size.



CERUSSITE CLUSTER FROM ELKHORN MINE.

with galena and pyrite, and in lesser amounts with tetrahedrite, in the ores of the Elkhorn mine and in all the galena ores of the district. It has commonly a dark-brown, resinous luster, is massive, and shows a coarsely crystalline texture. In the Elkhorn ores it varies from a very pale creamy brown, usually showing flakes of red in the quartzose ores, to a deep brown when associated with galena and a blue black when associated with pyrite. It is very rarely seen as a secondary mineral associated with pyrite and calcite in cavities in the original ore. In this case it forms well-shaped crystals one-eighth to one-fourth of an inch across, and is of undoubted secondary origin. The massive material of the ore body shows shattering, with cementation of the fragments by silica. Blende from the Elkhorn mine is commonly supposed to carry silver, and the red blende, especially, to carry high values in silver. This, however, has not been borne out by the assays made for the writer; in fact, owing to the common admixture of galena particles, it is impossible to obtain absolutely pure material for assay, and therefore there is some doubt in the case of this mineral, as well as in that of the pyrite, whether the silver contents are not derived from the galena.

Calamine (*hydrated silicate of zinc*).—This mineral occurs in drusy coatings lining cavities in the oxidized portions of the ore bodies of the Elkhorn mine. It forms radiated groups of spatulate crystals, usually somewhat stout and of the common form, in which the brachypinacoid forms the broad face and the prism is relatively small. The Elkhorn material is of two kinds. The first occurs associated with the limestone, in which case the calamine rests on a crust of pale yellowish-green, botryoidal material one-eighth to one-sixteenth of an inch thick. Above this there is often a film or thin crust of bright-green carbonate of copper, upon which the calamine rests in a mass from one-half of an inch to an inch thick, composed of bunches of radiating crystals. This material has a very delicate-green tint, although it is commonly transparent. The crystals show their form very distinctly, but are twinned and occur in groups, so that crystals for measurement are not obtainable. In the entirely oxidized parts of the ore body, where the limestone has been dissolved away and only the cellular films of silica are left, calamine occurs lining the cavities with thinner and more fragile crystals than those just noted. These crystals also are perfectly clear and colorless and rest on a film of silica. The derivation of the calamine is undoubtedly from the oxidation of the blende, and its occurrence in the mine is such as to leave no doubt on this subject. Small druses were broken open in which the cavities were filled with water and in which the calamine crystals were apparently still forming.

Cerussite (*lead carbonate*).—Very beautiful masses of crystalline cerussite were obtained from the upper workings of the Elkhorn mine. It occurs in six or eight stellate groups, the rays being formed by plates scarcely thicker than a sheet of paper, and sometimes reaching dimensions several inches across. Pl. LII is from a photograph of a specimen showing relatively small crystals. The more common occurrence is as a massive material coating galena, from which it is quite evidently formed. This material is usually clear and glassy, with a leady luster, and can be traced into the parent mineral. The galena alters along cleavage cracks, and every gradation may be observed between the fresh and unaltered material and the cerussite. Ashy-gray, loose-textured masses also occur, but are less abundant. In the upper workings of the Elkhorn mine large quantities of carbonate ore were extracted, the cerussite occurring in massive form and associated with various impurities.

Linarite (*hydrated sulphate of lead and copper*).—This mineral is rare, but good specimens with the usual azure-blue color, from the Elkhorn mine, were seen in the collection of Mr. Walter S. Kelley.

Chalcopyrite.—This occurs in the Dolcoath ores and rarely in the Elkhorn mine. It is massive and occurs associated with pyrite.

Gold.—Native gold was seen in the ores of the Dolcoath mine, particularly those in which the tetradymite has been partially or wholly altered. The color is deep bronze yellow.

Silver.—Native silver was abundant in the thoroughly oxidized portions of the Elkhorn mine. Its most interesting occurrence is in branching clusters of crystals, a few of which are shown on Pl. LIII. No large crystals were obtainable at the time of visit. These clusters occur attached, often only by the base or stem of the fern-like cluster, to the iron-stained siliceous decomposition product which forms the gangue of the upper part of the lode. Silver also occurs as sheets or scales in cracks and coating surfaces of less altered material. In the clusters the crystalline form is very clearly recognizable, though the material is not especially adapted for crystallographic study.

Pyrolusite (*black oxide of manganese*).—This occurs in little spots coating calamine, and as dendritic markings on the yellow, partially altered dolomite of the Elkhorn mine.

Azurite (*blue carbonate of copper*).—This is found in the Elkhorn mine in minute clusters or as a blue stain; also in numerous prospects, particularly the ores of the Copper King.

Malachite (*green carbonate of copper*).—This occurs as a green stain and in earthy masses in the oxidized ores and as green crusts in botryoidal forms associated with calamine in the Elkhorn mine. It is found only in small amounts. It also occurs in many prospects of the district.

Hematite and magnetite.—These occur, intimately associated, in the iron ores from the mines on the north side of Elkhorn Peak, near the summit. No specular or crystallized material was seen.

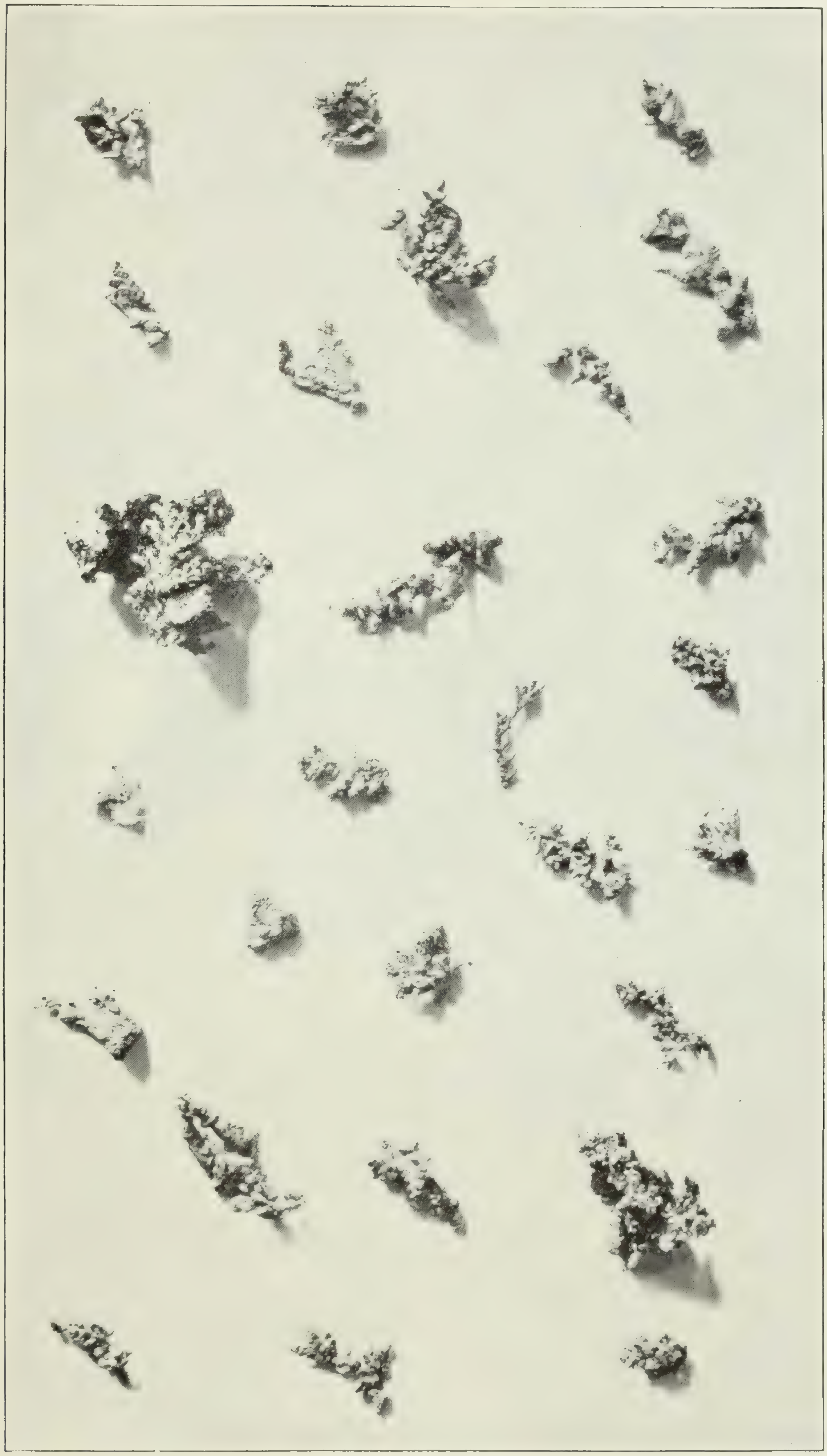
Limonite (*brown hematite*).—This mineral occurs as earthy masses

PLATE LIII.

PLATE LIII.

NATIVE SILVER FROM ELKHORN MINE.

This plate shows a number of pieces of arborescent and dendritic native silver from the ores occurring in the upper part of the Elkhorn mine. The specimens are very much smaller than many of those which were found in the development of the property. The silver occurs loosely attached to an oxidized siliceous gangue. The crystals are often flattened and elongated and form complex groups or aborescent forms, usually attached to the base of the fern-like mass, although the specimens show definite crystal forms. The edges are often rounded and the faces dull, so that the material is not fitted for crystal measurement. The forms, however, are undoubtedly those common to native silver and present no novelty in this respect. Although native silver was of common occurrence in the uppermost parts of the oxidized ore bodies at the mine, none of the common wire silver, seen as an alteration product of the rich silver sulphides at so many mines in the State, has been found at Elkhorn. Scales and plates of native silver also occur in cracks in masses of amorphous white and red silica.



NATIVE SILVER FROM ELKHORN MINE.

at many places in the district. It is common in the rusty outcrops of mineral veins.

Descloizite (*vanadinite of lead and zinc*).—This occurs in thin, mossy, dull yellow-green crusts of minutely crystalline surface, coating cavities in a deposit of greenish and red-colored amorphous silica from the hanging-wall ore body of the 1,300-foot level of the Elkhorn mine.

Aurichalcite (*basic carbonate of zinc and copper*).—This occurs in bunches of pale-green, silky needles, filling cavities one-half to three-fourths inch across in oxidized siliceous ore of the Elkhorn mine.

Smithsonite (*zinc carbonate*).—This is found associated with calamine on dolomite fragments of oxidized parts of ore bodies. It forms gray crusts 1 mm. thick, with drusy surface, covered by a second crust of pale apple-green botryoidal material showing both radial and concentric structure. This latter crust varies from 1 to 5 mm. in thickness, and the green tint is due to a small amount of copper. Malachite crusts often rest upon the smithsonite and are in turn coated by green calamine.

Pyrrhotite (*magnetic pyrite, iron sulphide*).—This mineral occurs in small amounts at several of the ore bodies of the district. In the Elkhorn mine it is found associated with pyrite, as a massive coating around cubes of pyrite in the white dolomitic marble of the bottom levels of the mine.

GANGUE MINERALS.

The minerals just enumerated occur associated with the valueless gangue minerals. These are few in number, embracing quartz, calcite, dolomite, garnet, and diopside.

Quartz (*crystalline silica*).—Quartz is almost universally present in the ore bodies of the district. It forms the hanging wall of the Elkhorn mine, and is abundant also in the foot-wall bodies. It occurs in every form from coarsely crystalline to extremely fine crystalline textures, and is clearly a replacement quartz in many cases, while in others it has the coarse comb structure characteristic of the filling of open spaces. Groups of large crystals are rarely found, and the mineral has no especially interesting feature aside from its genetic relations.

Calcite (*lime carbonate*).—This occurs abundantly throughout the Elkhorn mine, where it forms crystalline coatings of well-shaped rhombohedra in drusy cavities in the lead ores associated with zinc, and also occasionally in stalactitic forms in small cavities and water courses.

Dolomite (*carbonate of lime and magnesia*).—This forms the white marble foot-wall country rock of the Elkhorn lode. It is very uniform in texture and in composition. No well-shaped crystals have been seen.

Garnet (*variety grossularite*).—This lime-alumina garnet is common in the metamorphic rocks of the district. It occurs as a gangue mineral in the Dolcoath mine, where it is massive and is mixed with diopside in the stratum containing the ore. It is the product of the alteration by contact metamorphism of an impure limestone. The color is usually a cinnamon brown, and the mineral alters to a greenish chlorite. Crystals are seen penetrating the calcite in this ore. It occurs mixed with magnetite in the ore from the iron mines on the summit of Elkhorn Peak, where it is glassy, and has a dull greenish-yellow color.

Diopside (*lime-magnesian pyroxene*).—This form of pyroxene is found abundantly as a contact mineral throughout the district, but its only occurrence as a gangue mineral is in the Dolcoath mine, where, as just noted, it is mixed with garnet. It has a pale yellowish-green color, and occurs only massive, no crystals being observed.

Serpentine (*hydrated silicate of magnesia*).—This mineral occurs as an alteration product of diorite in the Elkhorn mine, and also in the railroad cuts near that property. It occurs also as an alteration product of garnet (?) in shells surrounding fragments of limestone included in the andesites of Elkhorn Peak. It is not, strictly speaking, a gangue mineral.

Axinite (*boro-silicate of aluminum with varying amounts of iron and manganese*).—This mineral occurs both as a rock constituent in the sediments altered by contact metamorphism and as the filling of little veins in such rocks. It is found abundantly in coarse crystalline masses in such veinlets at the prospect tunnel driven in from the creek bed 1½ miles above Elkhorn. The specimens are of a dull-grayish plum color, in lamellar aggregates of crystals usually striated. It occurs associated with calcite.

Tourmaline (*basic or subsilicate of boron, alumina, potash, lime, magnesia*).—This mineral occurs sparingly in the contact-metamorphic rocks that inclose some of the smaller ore bodies disclosed by shallow prospect pits on the eastern side of Alpreston Gulch and vicinity. It also occurs as stout black crystals, often having a rusty coating, in the center of altered fragments of marmorized limestone included in the andesite.

Epidote (*orthosilicate of lime, alumina, and iron*, $H\,Ca\,(Al\,Fe)_3\,Si_3\,O_{13}$).—This occurs abundantly in the contact-metamorphic rocks formed from impure limestones. It is common near Black Butte, where it forms fascicles whose fibers are several inches long. This material is associated with calcite and axinite.

Wollastonite (*silicate of lime*).—This occurs as a constituent of the contact-metamorphic rocks, particularly the slightly impure marbles, in which ore bodies occur. It is seldom in masses recognizable to the naked eye.

Microcline.—This mineral occurs in white, coarsely massive form in the syenite dikes of Queen Gulch, but is not associated with the ore deposits. Various other minerals occurring as rock constituents are mentioned in the petrographic description of the igneous and the contact-metamorphic rocks.

PARAGENESIS.

A study of the ores from the Elkhorn mine shows that the primary sulphide minerals were deposited at the same time. There is, it is true, oftentimes a distinct coating of pyrite about isolated grains of galena, but in the massive ore the minerals interlock and show no evidence of difference in age. Moreover, there is no crustification in the primary ore; later fracturing has sometimes permitted infiltrating solutions to deposit secondary quartz which, though usually barren, does sometimes hold galena and tetrahedrite. The pyritic ore from the lower levels sometimes shows drusy cavities coated by distinct crusts. In this case the oldest crust resting against the primary sulphide ore is sometimes pyrite, and more often the following succession is seen:

A. Pale-yellow, opaque blende.
B. White calcite in well-shaped rhombohedra.
C. Pyrite in well-formed pentagonal dodecahedrons.
D. Clear and transparent resinous blende in distinct crystals.
E. White calcite in well-formed rhombohedra.
F. Quartz crystals in clusters.
G. Isolated pyrite crystals resting on the points of the quartz.

The entire succession is not always shown. It is evident that observations made upon these small druses can not be relied upon to furnish any conclusive evidence as to the manner of deposition or the chemical changes involved in the formation of the Elkhorn deposits.

As to the association of the minerals, it has been observed that where the ore contains tetrahedrite it commonly holds a light pale-brown zinc blende, and that pyrite is either absent or is present in insignificant amounts. Bournonite sometimes, though rarely, occurs with tetrahedrite, but is never found with blende. As a rule, both bournonite and tetrahedrite occur only in quartz and are not found as direct replacements of limestone, while the ores that contain the most blende are low in silver.

CHAPTER VIII.

THE ELKHORN MINE.

History of the property.—The ore deposit known as the "Elkhorn" mine was located as the Holter lode on January 2, 1875, and was worked nearly continuously from that time until November, 1899. The general history of the property has already been mentioned in giving that of the district. The New Elkhorn Mining Company stopped work in the mine in the autumn of 1899, and as the pumps were withdrawn, the surface machinery dismantled and sold, and the mine practically abandoned, it was generally understood that this great producer was worked out and the last chapter of its history completed. The entire property, including such surface improvements as were of value, was sold to two successful mining operators for $20,000 early in 1900, and it was generally supposed at that time that only the dump heaps would be worked. The new owners decided, however, to reopen the upper levels of the mine, and the property is now (May, 1901) being equipped with the necessary machinery for working, and promises to again become a producing property. The abandonment of the mine by the English corporation was primarily due to the exhaustion of the rich ore bodies, for although more or less ore remained, it was of too low grade to pay expenses, owing to the heavy expenditures necessary in pumping the mine, which were over $1,000 a week; this, and the small number of men scattered over so large a mine working the low-grade patches and remnants of ore bodies left in previous years, made the cost per ton excessive. Thus the actual cost of mining exceeded $15 per ton, including all expenses. Milling cost $9, owing to baseness of the ore, and for a long time the reduction works were run on a profit of only 50 cents per ton, thus necessitating very close working.

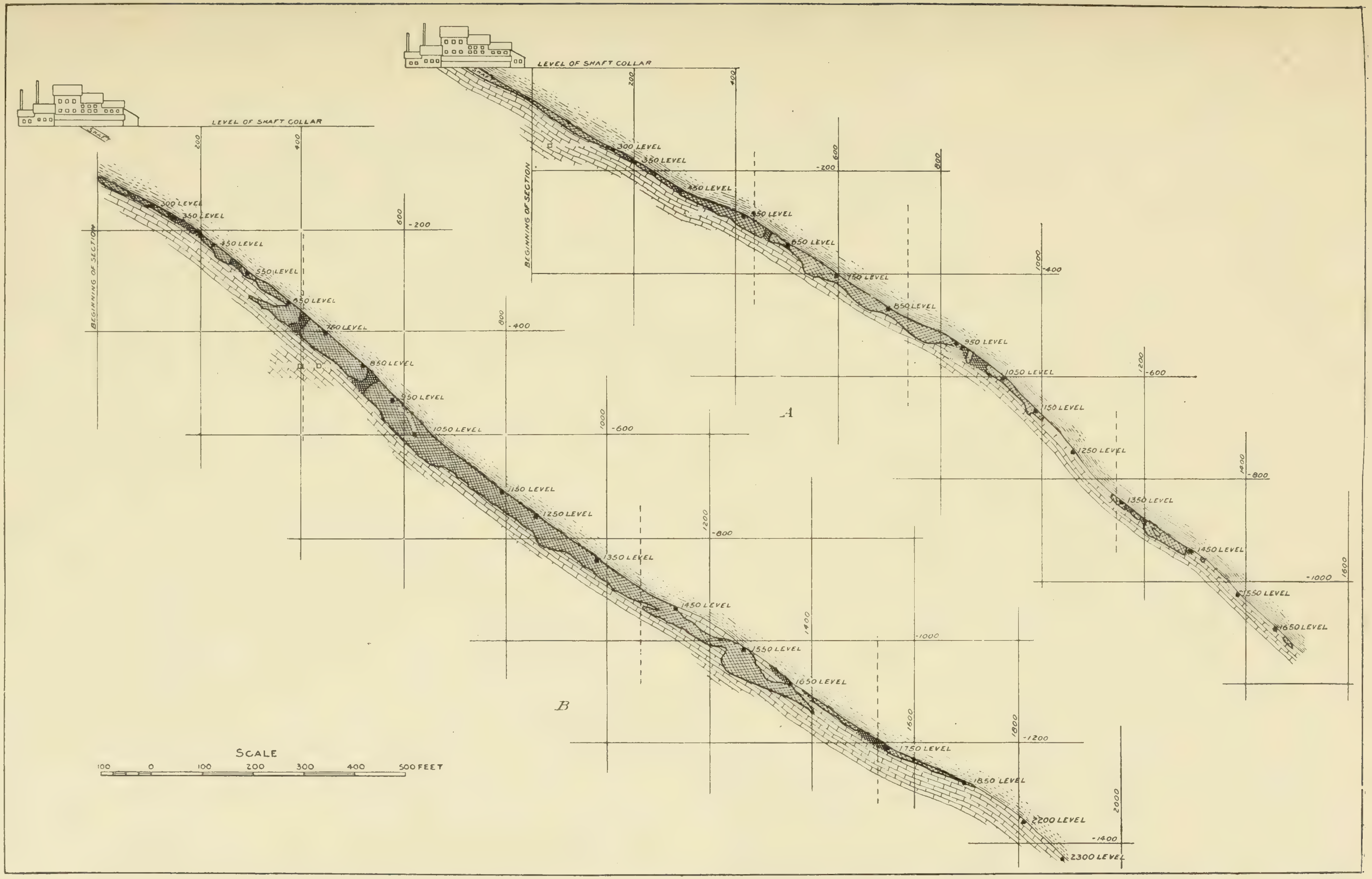
General features of the ore deposit.—The ore deposit does not constitute a true vein, though commonly spoken of as a vein or lode. The ore occurs in two principal shoots lying on the under side of folds—i. e., in the saddle of the folds—and conforming to the dip of the stratified beds in which they occur. These ore bodies are found along a bedding plane between indurated shale (hornstone) and dolomitic marble. This contact plane was followed in mining and has commonly been spoken of as the lode. Although there has been some slipping and movement along this plane, the contact is not mineralized, nor does it show any vein quartz or other lode material except in the steeply pitching arches underneath which the ore bodies occur. The ore deposits consist of more or less irregular bodies of rudely lenticular cross section lying against the hanging-wall hornstone, and as isolated masses forming so-called "chamber" deposits in the underlying dolomite. The hanging-wall bodies consist of quartz carrying ore minerals and are practically continuous from the top to the bottom of the mine. The lead chambers are isolated bodies connected by fissures or rusty stringers with quartz ore shoots, but of irregular shape and position, and often of large size. They are not cave deposits, and the term "chamber" applies only to the caverns left by the extraction of the ore, no original cavernous open spaces occurring. While there may be honest doubt concerning the formation of galena deposits in open caverns in limestone at many American localities, the facts to be described herein preclude any such theory of formation.

Topographic relations.—The ore deposits occur, as may be seen by reference to the map, Pl. XLV, in the relatively broad and open valley of Elkhorn Creek, where the more readily weathering limestones have been eroded into a basin whose bottom is now filled and leveled by morainal material. This position, as may be seen from the topograpic map, Pl. XLII, is a relatively low one and receives the drainage from a large area of impervious rocks forming the high peaks near by. It is, as it were, the apex of a funnel composed of the snowy amphitheater of Elkhorn and Crow peaks and their adjoining ridges. Though the creek bed is in morainal wash, so that the stream before diversion often carried flowing water past the mine, a large part of the precipitation and run-off of the northern part of the district finds its way into the altered limestones, in which it has formed subterranean waterways. It should, however, be remarked that no large caves have been found, and the smaller waterways noted in underground exploration are evidently later and not in any way connected with the ore bodies.

Geological relations.—The ore deposit occurs in a dolomitic limestone forming massive beds and overlain by altered shale. The strata dip steeply, the angle varying from 35° to 55°, this attitude being due to the uplift and folding of the entire Paleozoic and later rocks into a series of parallel mountain folds that extend eastward to the valley of the Missouri at Townsend. As shown in a previous chapter, all the sedimentary strata seen in this district form part of the eastern side of an arch, the spur formerly occupied by the west limb of this anticline being now occupied by the granite batholith. This structure, as understood from the surface relations near the Elkhorn mine, is shown in the cross section 2 of Pl. XLVIII. The half arch now forms a monoclinal fold composed of all the various beds seen in the Elkhorn district. The uniformity of the monocline is, however, disturbed by several minor corrugations which have been noted in the earlier chapters. The ore deposit occurs in two of these lesser flexures, which coalesce near the surface and form one relatively broad arch. These arches pitch steeply to the north. The gabbro-diorite intrusion, which has been described in a previous chapter, breaks through the limestones and shales, and has shattered them, sending out forks and tongues of diorite and allied rocks into these irregular breaks. Such intrusions are seen on the surface to the northwest and southeast of the mine, and are encountered in an exploratory drift under ground, and, though they have no direct connection with the ore bodies and do not make ore where they occur, it is believed that the main gabbro mass is the source from which the metallic contents of the deposits have been derived. These lesser diorite intrusions are seen in the mine in the long south extension of the 650-foot level.

Outcrop.—South of the mine buildings, shown in Pl. XLIII, the outcrop of the ore body is obscured by morainal débris and has not been found. It has not been recognized in the railroad cut opposite the town, and in fact at that point the diorite breaks across the contact plane along which the ore body occurs farther north. To the north of the mine the outcrop is seen in the railroad cut back of the boiler house, where the rocks have a strike of N. 50° W. and dip at 30° to 50° NE. Some 30 feet of the foot-wall sand rock or dolomite is exposed, with 150 or 200 feet of thin-bedded argillaceous shales lying upon it. The outcrop could not be traced on the surface beyond this point, but is said to have been opened by prospect pits at a number of points. Silicified limestones occur immediately south of the tailings dam on the south side of the mill. The rocks are part of the Keene limestone and show brecciation and replacement by siliceous waters. It is therefore evident that the mineralizing solutions were not confined to the immediate channels in which the ores of the Elkhorn mine were deposited, though, so far as known, the ore bodies formed near by are not workable.

Hanging-wall hornstone.—The ore bodies are sharply delimited by a hanging wall of argillaceous rock. This rock is dense and tough, and corresponds to what some geologists call hälleflinta, but which in this report has been called hornstone, following the nomenclature of Rosenbusch. The rock is well bedded, as shown in Pl. L, *B*, but does not possess either a shaly or a slaty cleavage, but breaks into splintery fragments along a system of fine jointing, thus forming cubical masses. The term argillite does not apply to it, as strictly speaking that name implies a slaty or schistose rock. The character of this hanging-wall rock is best seen at the 1,050-foot level where a cross cut drift has been driven 120 feet into this rock. A careful study of the rock was made, samples being picked off every foot of the distance along this hanging wall. It was found to be hard and compact and to show no slaty cleavage or fracture, although the original stratification lines are



VERTICAL TRANSVERSE SECTIONS OF ELKHORN MINE.

A, Across north hanging-wall body; *B*, across south hanging-wall body. Rectangular blocks represent limestone; light cross hatching represents ore extracted; heavy cross lining represents ore in place; parallel broken or dashed lines represent slate.

plainly seen. It varies from a flinty, siliceous type, carrying 94 per cent of silica and 2 per cent of lime, to very argillaceous rock practically free from lime. In the mine workings this rock shows a platy fracture, which might be taken for slaty cleavage, but which is in fact due to slight movement along the contact.

Three other hanging-wall crosscuts have been driven in the mine; one on the 300-foot level north, a short one from the 1,250-foot south stope, and one from the 1,250-foot south level. The first two were not extended far enough to pass through the slate which forms the hanging wall of the lode; but the third at a distance of 60 feet encountered a grayish-blue limestone. On the line of contact a soft clay seam occurs, which indicates faulting movement or slipping on the bedding plane. This clay carries 2 ounces of silver per ton. Somewhat higher assays were obtained from this same contact at the surface, where it is exposed in a railroad cutting, and also in a prospect shaft recently sunk. These are the only points at which this upper or second contact is exposed, but proper exploration might develop some new ore deposits on this horizon.

Foot-wall dolomite.—The dolomite or marble in which the ore occurs forms the uppermost member or stratum of the limestone series herein designated the Cemetery limestone. The foot-wall crosscuts show this rock to be of very uniform character. The bedding is rather massive, and in a crosscut driven for a distance of over 200 feet horizontally a few obscure partings or stratification planes are seen. They are marked by films of argillaceous matter, and one of them, occurring at 35 feet beneath the slate hanging wall of the ore body, is very constant in character and is commonly called the foot wall of the ore body. The argillaceous material is part of the limestone, however, and shows no clay or slickensides or other evidence of movement. The rock is a crystalline dolomite of medium and even grain, usually white, but varying to a bluish-gray or yellow color. It is so uniformly crystalline that it is properly called a marble. A partial analysis, made by H. N. Stokes in the chemical laboratory of the Geological Survey, showed the amount of magnesian carbonate to be practically the same in the different varieties from the mine.

White dolomite contains $MgCO_3$, 44.0; residue (silica, Fe_2O_3, etc.), 0.4; iron, etc., 0.3.
Blue dolomite contains $MgCO_3$, 43.7; residue (silica and iron), 1.3.
Yellow dolomite contains $MgCO_3$, 42.5; residue (silica and Fe_2O_3), 2.3; iron, etc., 1.0.

The yellow rock is the oxidized form found near the ore bodies in the upper part of the mine. It commonly shows more iron and silica than the white dolomite, and the fracture planes are marked by dendritic films of manganese.

The rock has a very pronounced granular saccharoidal texture and has been designated by the miners a sand rock, since it is sometimes so loosely cemented as to crumble, under slight pressure, to a white sand. No evidence was found to show that the dolomitization was the result either of metamorphism or of the mineralizing waters which produced ore deposition, but it is inferred that the chemical character of the rock is original, as otherwise the shrinkage in volume resulting from dolomitization would have left some evidences of such action.

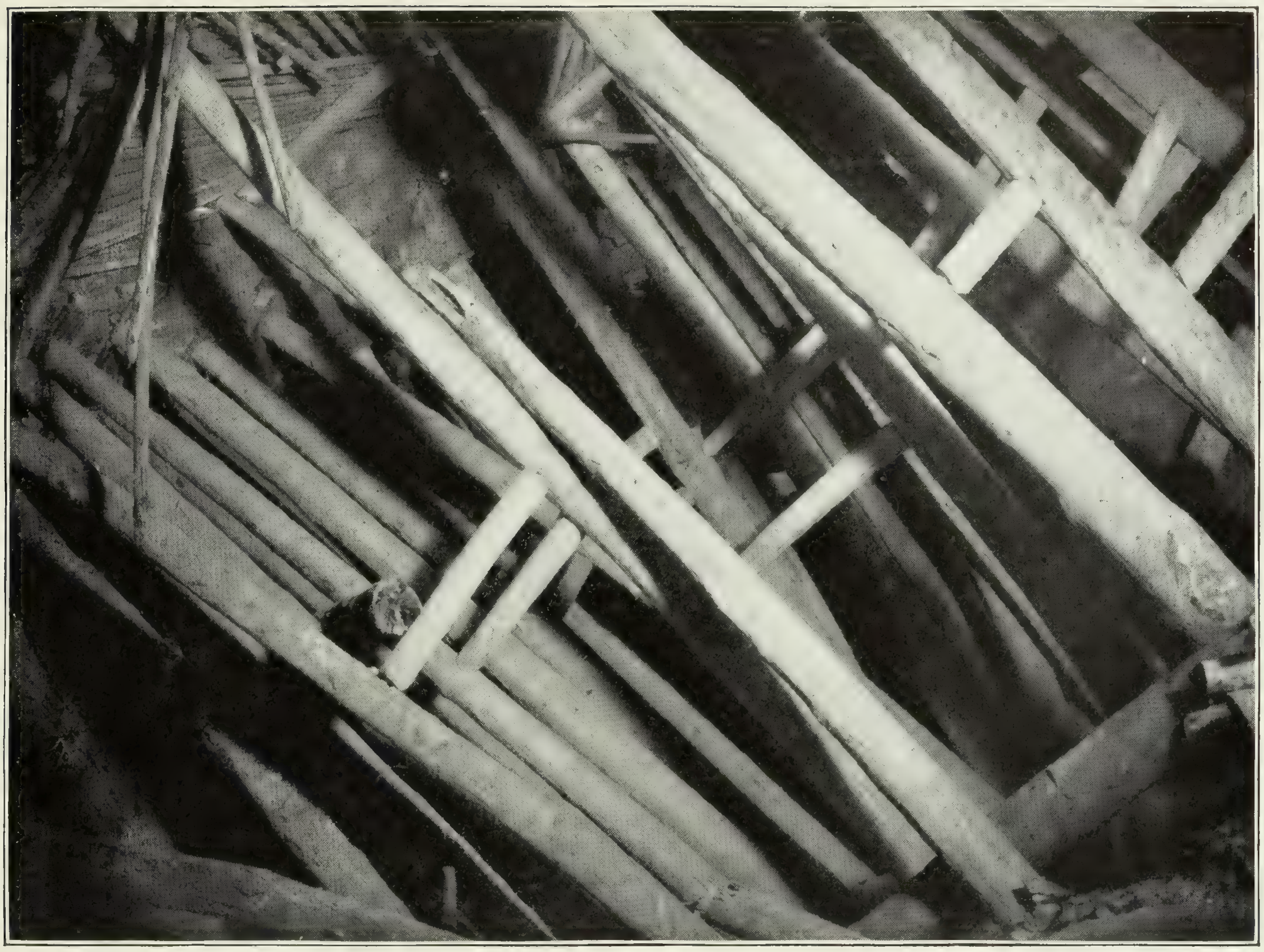
Strike and dip.—The contact on which the main ore bodies occur varies in strike, owing to the arching of the strata. Between the ore shoots it is N. 10° W., and this is very nearly the strike farther south, as shown by the prospecting levels. This conforms nearly to the general strike of the rocks near by. The levels shown on the map of the mine, Pl. LVII, follow this contact rather closely, leaving it at but few places, and then only for short distances. The levels, therefore, show very plainly the warping of the strata, and that the change in strike is not only a horizontal one, but affects the pitch of the folds as well. The changes in dip are less marked, varying from 35° to 55°. The dip of the ore body is indicated in the vertical transverse cross section of the ore body in Pl. LIV, *A* and *B*, and may also be seen in Pl. LI, where the rails on which the mine skip rests are laid parallel to the dip of the hanging-wall slate.

THE ORES.

General character.—The ores of the mine are classed as milling ores and smelting ores. The first kind are quartzose and come from the hanging-wall bodies almost entirely and embrace only those ores that can be treated in the mill. In the early history of the mine the product was entirely free milling, but as depth was obtained the ore changed in character and could be treated economically only by chloridizing roasting. The milling ore increased in baseness with depth, until at the time the mill shut down no other mill of this character was known to treat ores so base. As the natural result, the cost of treatment ran up until at the time of closing down it closely approximated the cost of treatment by the smelters.

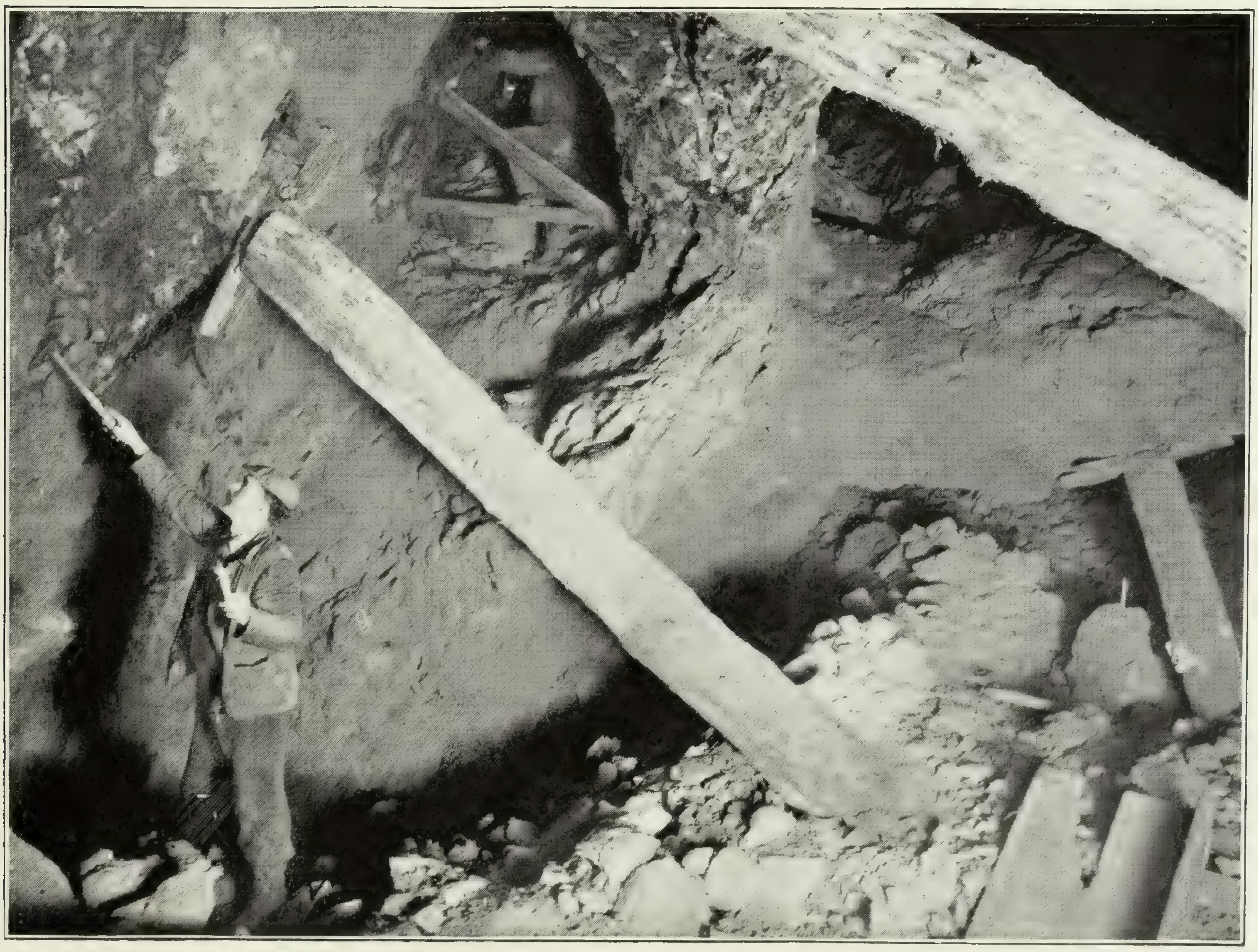
The smelting ore consists of galena, together with quartz, some zinc blende, and a lesser amount of pyrite. In the upper part of the mine these minerals were oxidized, and as a consequence the mine yielded large amounts of carbonate ore, which was sent to the smelter when it carried 20 per cent of lead. In the deeper levels and in the lower part of all the foot-wall ore bodies only sulphide ores occur, and these, when brought to the surface, contain much white limestone and were therefore cobbed by hand and sent to the smelter. No attempt was made at ore concentration, and the waste heaps of the mines contain large bodies of low-grade galena ore.

Value of the ores.—No average value can be given for the two kinds of ore for the entire mine. In 1897, 13,526 tons of ore were milled,



A. CHAMBER IN 1,250-FOOT SOUTH STOPE, ELKHORN MINE.

The timbers are 60 feet long and their closeness was necessitated by the looseness of the slate roof.



B. SOUTH END OF 950-FOOT SOUTH STOPE, ELKHORN MINE, LOOKING SOUTH.

The timbers are headed against the slate and they rest on dolomite marble. From flash-light photograph taken by C. F. Pearis

which showed an average silver content of 36.3 ounces and gold 0.0031 ounce per ton. The roasted ore has for the last three years averaged about 39 ounces of silver per ton. The shipping ore sent to the smelters averaged, during 1897, 135.4 ounces of silver and 0.152 ounce of gold per ton, with 12½ per cent of lead. At the average selling prices this gave a value of $67.78 per ton.

In the early history of the mine very much richer ores were treated. Assays of special samples show very high values. Thus, partly altered galena from the 170-foot level assayed 4,185 ounces of silver per ton. Oxidized ore, mostly massive cerussite with a little malachite, from the 1,450 foot-wall ore body assayed, per ton: Silver, 1,447 ounces; gold, 8 pennyweight; lead, 46½ per cent; copper, 5½ per cent.

Samples of the very zincky ore vary considerably in silver contents. One from the 1,750 foot-wall body, which was fairly representative, assayed 45 ounces of silver and 2 per cent of lead. A sample of the white blende contained 14 ounces of silver per ton and no lead. One of the brown zinc blende yielded 105 ounces of silver per ton and 4 per cent of lead. Another specimen containing large amounts of resinous blende and of the dark-colored blende, or "black-jack," gave 45 per cent of zinc, 3 per cent of lead, and 15 to 20 ounces of silver. In general the reddish zinc has been supposed to carry high silver values, but in the specimens whose assays are given above the silver values are probably derived largely, if not wholly, from included grains of galena. The smelter returns show that the ore shipped averaged over 20 per cent zinc, and as the penalty is 50 cents for each per cent over 12 in sulphide ore, it will be seen that the cost of treatment was materially increased. The pyritic ore, of which only small quantities have been mined, is usually low in silver. A special sample showing an admixture of galena and pyrite yielded on assay 16.59 per cent of lead, 18.59 per cent of iron, 15 per cent of zinc, with one-tenth ounce of gold per ton, and 54 ounces of silver. A sample from the 1,750 pyrite body contains 3 to 10 ounces per ton of silver. Although native silver is of common occurrence in oxidized portions of the deposit, no free gold has, so far as the writer knows, ever been found. The ratio of gold to silver in the ores is very constant and approximates 1,000 ounces of silver to 1 ounce of gold.

The bullion from the mill is commonly between 850 and 900 fine, the impurity consisting mostly of copper. For some years while the mill was running on base ore, without any special attempt at close saving, the bullion ran as low as 400 fine.

The fine particles of ore carried up in pumping the mine waters pass through settling tanks, in which the slimes are caught. These slimes have averaged over 200 ounces of silver and 4 to 5 per cent of lead, and the waste water from the cobbing house yields slimes carrying 77 ounces of silver and 4 per cent of lead. These results show the brittle character of the rich ore. Car load lots shipped in 1894 gave assays as follows:

Sulphide ore: Zinc, 32.6; silver, 180.6; gold, 0.13; lead, 14.
Oxidized silver: Zinc, 17.3; silver, 223.3; gold, 0.17; lead, 12.8.

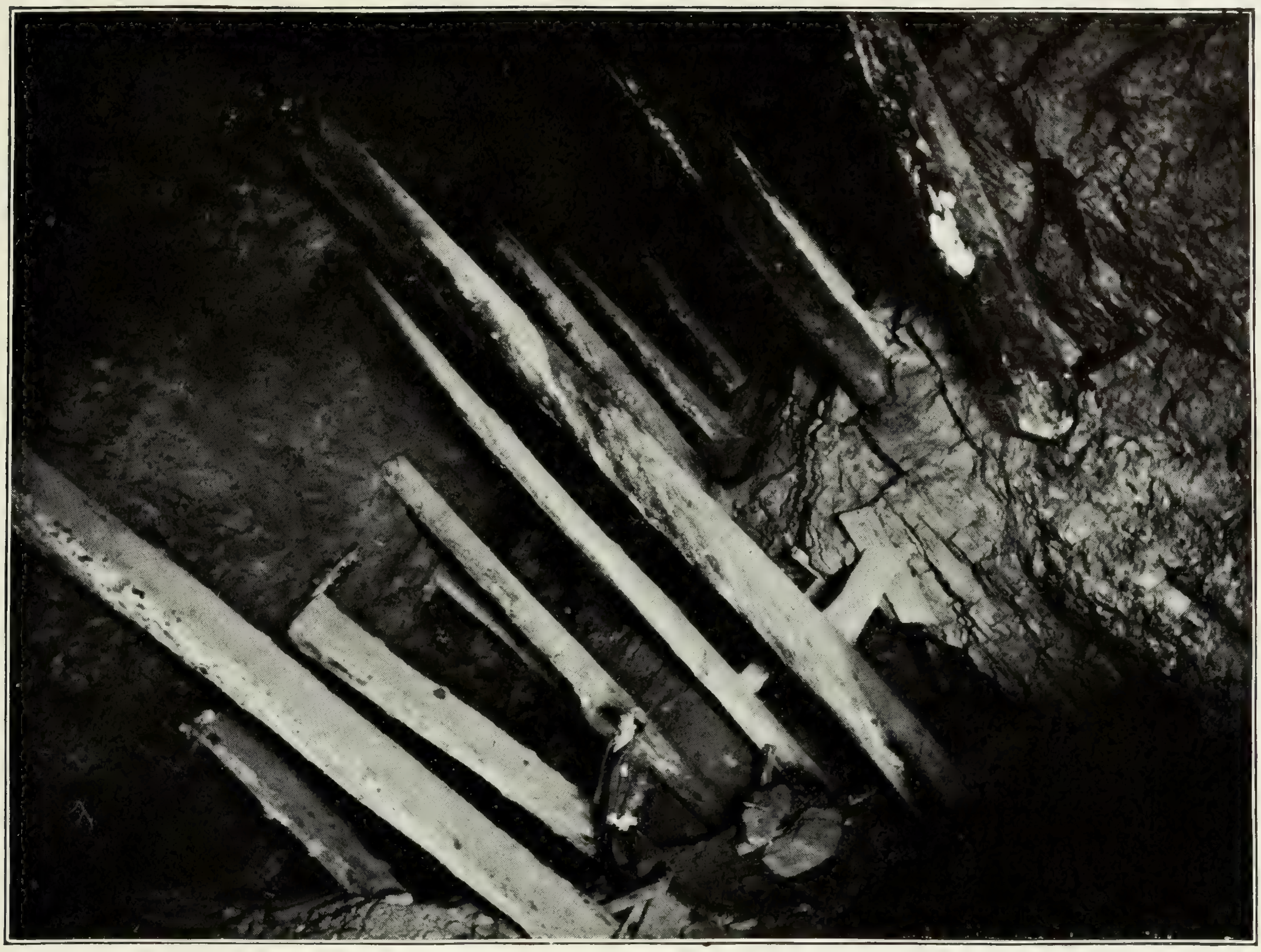
MINE WORKINGS.

The mine workings are shown on Pl. LVII, which the writer has been permitted to reproduce by the kindness of Mr. Kelley, the former manager. The main working shaft is an incline driven along the slate-dolomite contact. The incline goes down on the dip a part of the way and then bends so as to obtain an easier slope. It has an angle of 35° to 55°, the inclination varying with the undulations of the slate bedding plane that forms the roof. The roof is usually solid, and needs only upright timbers for support, caps and lagging being used in the upper part of the mine. There is no division into compartments. The ore is hoisted in a two-platform skip, on which the mine cars are run directly from the levels, as shown in Pl. LI.

In the later development of the mine, levels were driven at every hundred feet measured on the slope. These levels were run out north and south from the shaft; but owing to the nearness of the end line, the north levels are relatively short, and no prospecting has been done in that direction. On the south a number have been driven beyond the main ore body, and one (the 1,550) for a distance of nearly 2,000 feet.

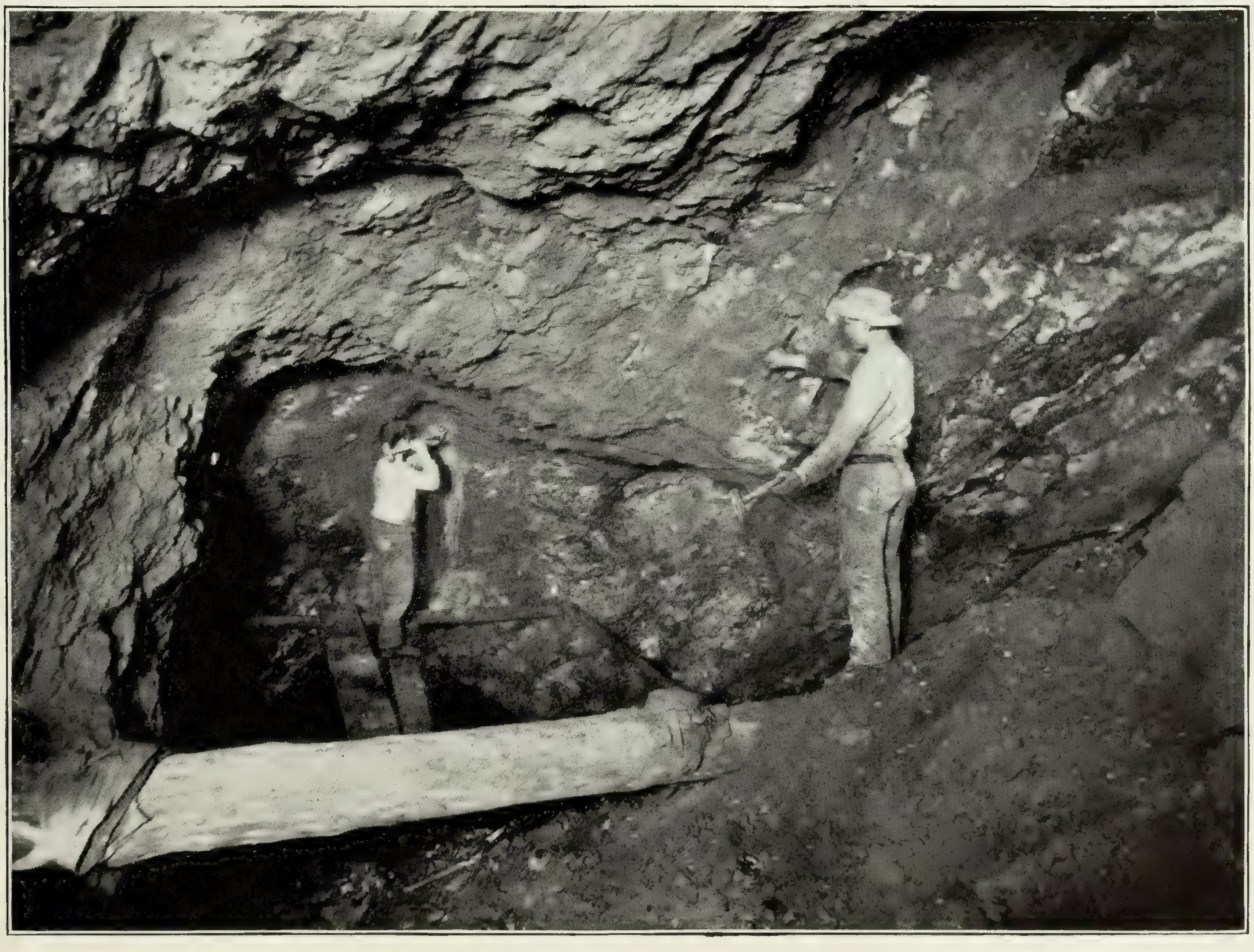
The regularity with which the main ore body maintains its position has permitted this relatively simple exploration, and as the quartzose ore bodies all come to the slate hanging wall the levels are sure to cut them. On the contrary, the chambers of silver-lead ore found in the dolomite occur without order or arrangement, and as a consequence the foot-wall crosscuts and exploration work have been very irregular. An instance of the luck of mining, and the fact that the rocks in the immediate proximity of the lead chambers show no indication of their presence, was the driving of a level past a foot-wall body, though a shell of limestone but a little over a foot thick separated it from the level.

The mine stopes are of course very irregular, owing to the extremely irregular shape of the ore bodies. They vary from small cavities a few feet across (Pl. LV, *B*), through which one can scarcely crawl, to great caverns 60 feet high. In general the hanging-wall slate needs support, as it has a tendency to shell off. Simple stulls and cap pieces were adequate in most cases (Pl. LVI, *A*), lagging being very rarely necessary. When the chambers became very large, as happens when the foot-wall bodies lie against the hanging-wall quartz, the timbering of these great caverns became a serious matter, and the few stulls at



A. THE 850-FOOT SOUTH STOPE OF THE ELKHORN MINE.

The timbers are headed against the slate and rest on the "foot-wall" streak in the dolomitic marble (the so-called sand rock). The view shows the large size of the hanging-wall main south ore shoot, at a point where the ore body extended from slate "hanging" to the foot wall. From a flash-light photograph taken by C. F. Pearis.



B. THE 1,450-FOOT STOPE IN LEAD CHAMBER.

This is an ore body entirely incased in the dolomite marble (the so-called sand rock). From a flash-light photograph taken by C. F. Pearis.

first used had to be supplemented with others until, as shown in Pl. LV, *A*, the timbers were so close one could scarcely pass between them.

ORE SHOOTS AND CHAMBERS.

GENERAL CHARACTERS.

The Elkhorn mine shows ore bodies of contrasted mineralogical character and different geological relations. The main ore channels follow the slate-dolomite contact, and as the slate invariably forms the hanging wall they are conveniently designated "hanging-wall" bodies. The ore is quartzose and is nearly all low enough in the baser metals to be milled. On the other hand, the so-called "lead chambers" or foot-wall bodies occur in the dolomite and are usually separated from the hanging-wall deposits by a greater or less thickness of that rock. The ore can not be milled, as it consists of silver-bearing galena with blende and some pyrite. This distinction of occurrence and character of ore is not invariable, since some milling ore occurs in the foot-wall bodies and some galena with the hanging-wall quartz.

MAIN ORE SHOOTS.

The occurrence of the great masses of ore constituting the hanging-wall ore shoots is best appreciated by reference to the map of the underground workings, Pl. LVII, and the transverse sections across the deposits, Pl. LIV, *A* and *B*. The mine map, being a horizontal projection, does not give a perfectly true picture of the shape and extent of the ore bodies, owing to their dip, but the data for a projection or a longitudinal section on the stratification plane of the rocks were not obtainable.

It is apparent from the map that there are two main channels of ore deposition, one to the north of the mine shaft, the other to the south, the latter being much the larger. Both are very irregular in shape, and their plan presents a striking resemblance to the maps of the famous caverns of the world. The map shows that the south ore shoot is of much greater size than that north of the shaft, and that it has somewhat more regular boundaries. Both shoots are continuous from the surface down to the 1,750-foot level, but decrease in size downward and finally pinch out. The shoots show a stringer of ore connecting them in the upper part of the mine, notably the 350 level, where the centers or axes of the two shoots are about 300 feet apart, but as the shoots diverge in depth the connection was not observed.

Forms of the ore shoots.—It is difficult to describe or even to show by figures the form of the ore shoots, since they are very irregular. Cross sections of the two shoots are given in Pl. LIV, *A* and *B*. These were prepared from the mine maps, together with sketches and measurements especially made for the purpose and compiled under the direction of Mr. William Davey, who has been in charge of the underground work ever since the property became a producing mine. As he is familiar with every foot of the mine and knows all its peculiarities the sketches are believed to have a good degree of accuracy.

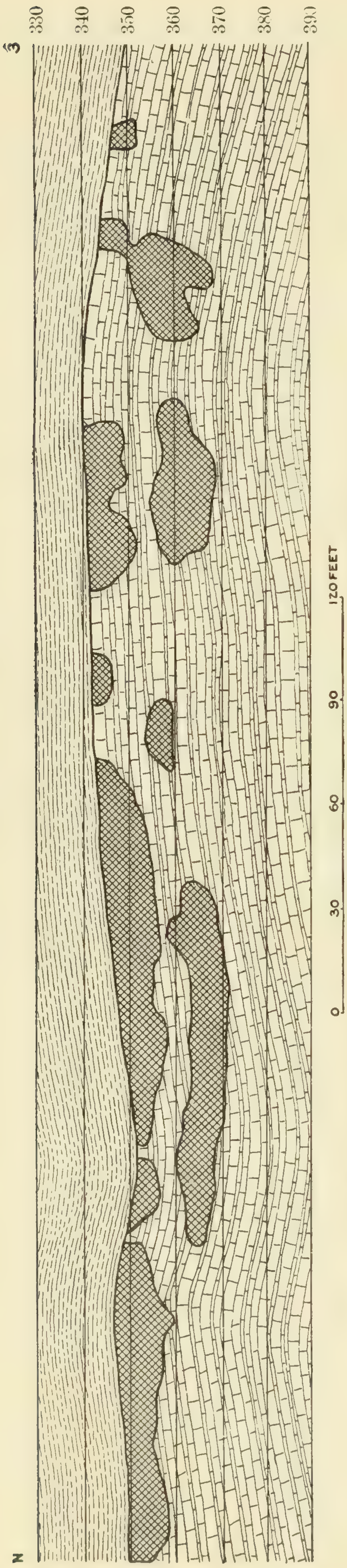


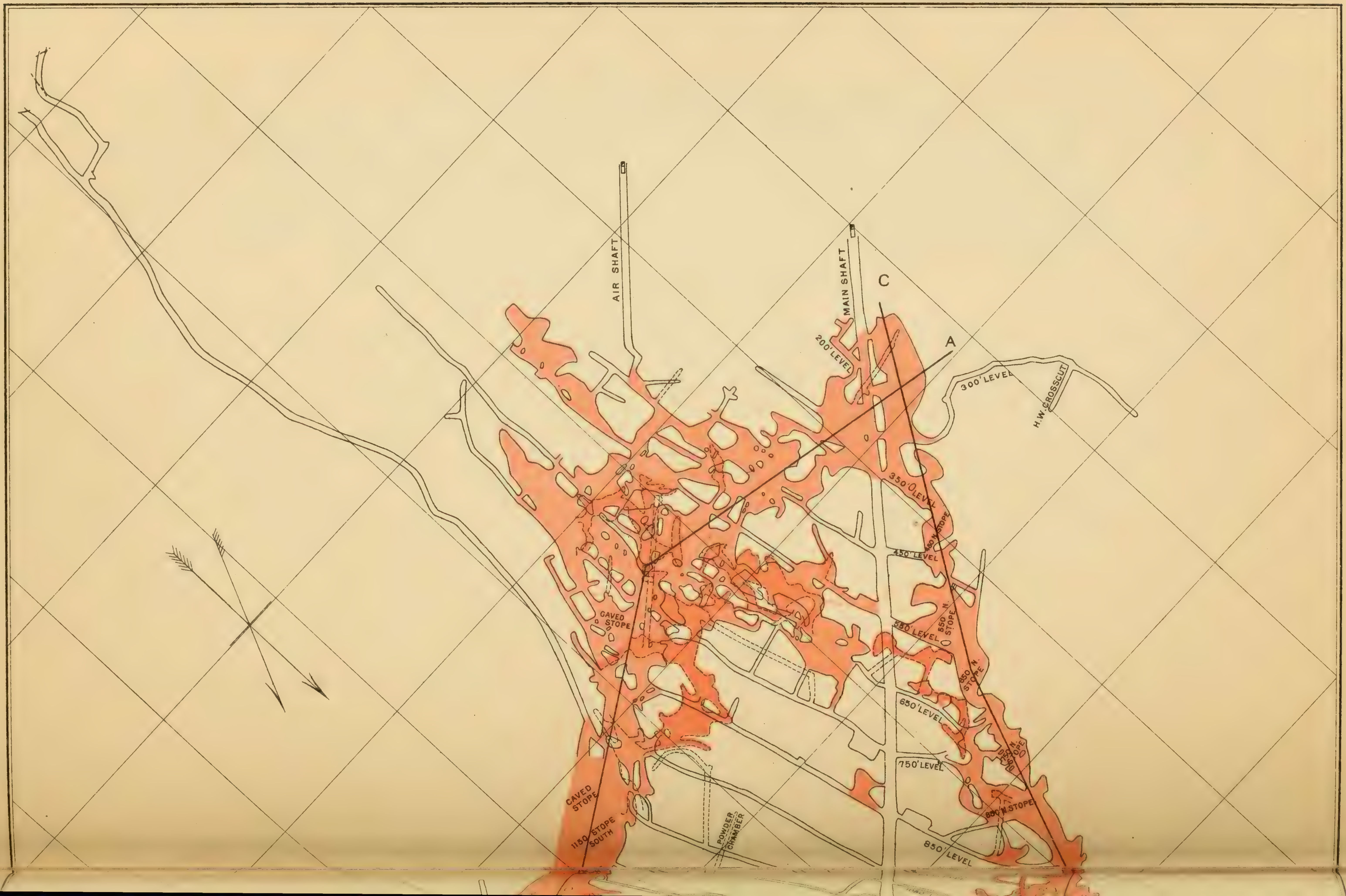
FIG. 73.—Section across the south ore body of the Elkhorn mine through the 650-foot level.

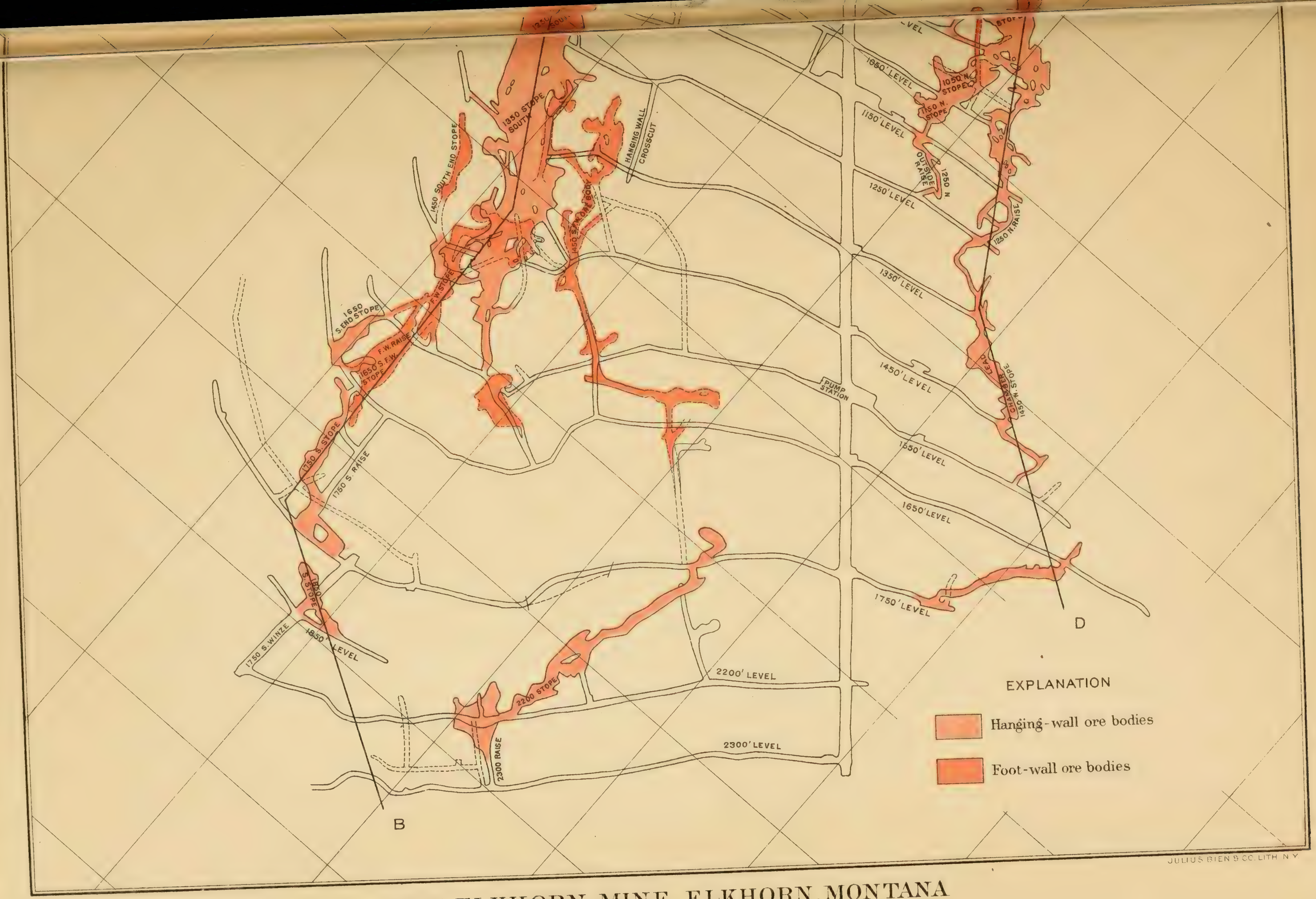
The cross sections of the two ore shoots are projected from the planes shown on the mine map by red lines. These lines change in direction at several points in order to give a representative cross section of the ore body, and the points where such change is made are shown on the sections by vertical red lines.

The cross sections of the south ore shoot, shown in fig. 73, convey a better idea of the size and shape of the ore body at the two levels selected as representative of the upper and lower parts of the deposit. These sections are true cross sections, since they are projected on planes cutting the deposit at exactly a right angle to the dip. Fig. 74 illustrates the lesser irregularities of one of the smaller ore shoots.

From a study of these cross sections and the horizontal projection of the ore bodies, it is apparent that while the ore bodies are irregular in size and shape they usually lie against the bottom of the slate, and hence have a very regular roof or hanging wall; that their bottom is more irregular, but conforms in the larger bodies to a plane parallel to the hanging wall. There is a marked tending toward an elliptical cross section, the ore bodies being very much wider than they are thick, so that the greatest axis of the ellipse is parallel to the strike of the inclosing strata. The size of the ore bodies varies rapidly from place to place horizontally and on the dip. In general it is greatest in the middle depths of the mine.

Peculiarities of the hanging wall.—The contact between the slate and limestone is very sharp, and in the mine workings the


AIR SHAFT
MAIN SHAFT
C
A
200' LEVEL
300' LEVEL
H.W. CROSSCUT
350' LEVEL
450 N. STOPE
450' LEVEL
550' LEVEL
550 N. STOPE
650 N. STOPE
650' LEVEL
750' LEVEL
1050 N. STOPE
850 N. STOPE
850' LEVEL
CAVED STOPE
CAVED STOPE
1150 STOPE SOUTH
POWDER CHAMBER



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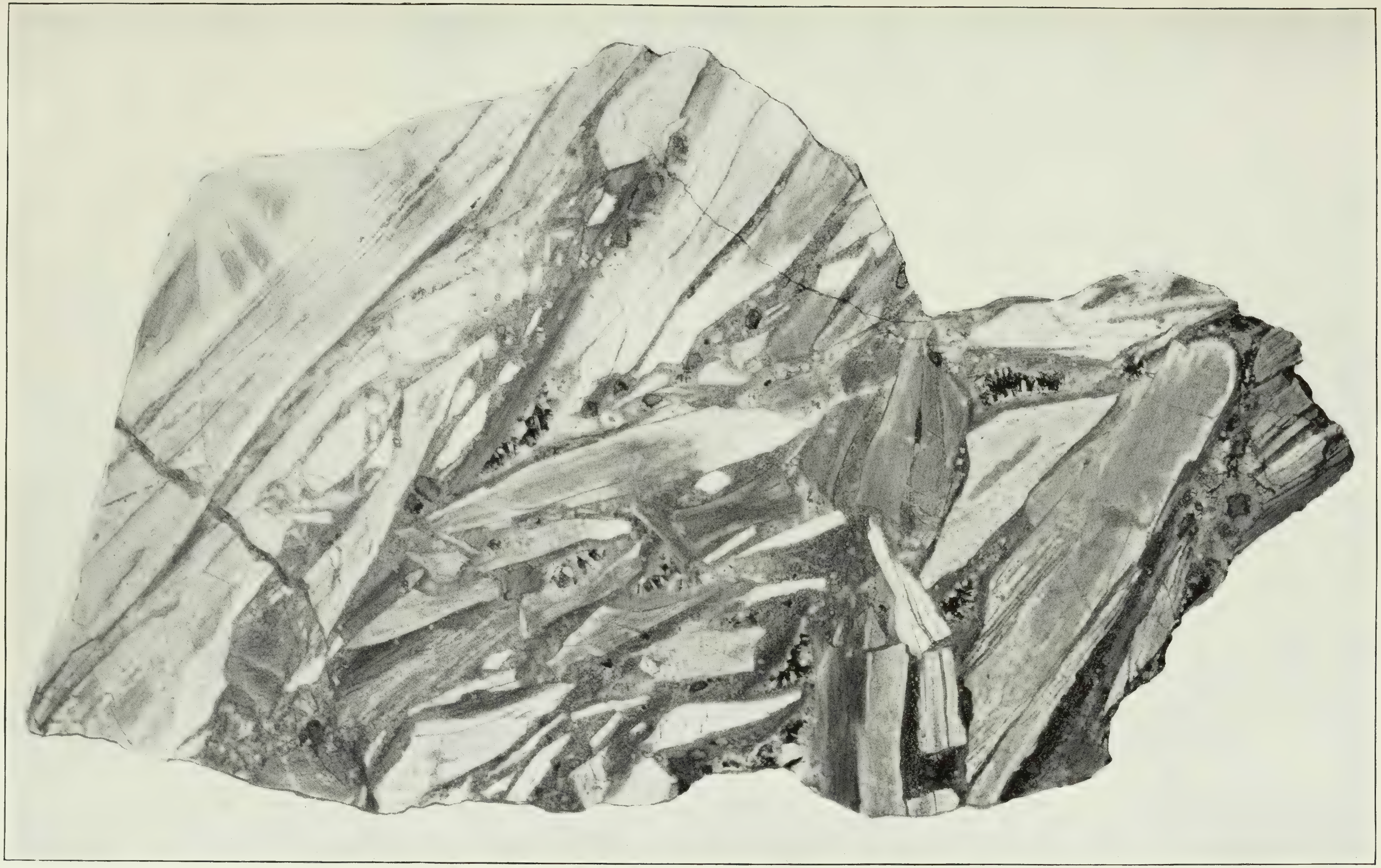
THE ELKHORN MINE, ELKHORN, MONTANA

PLATE LVIII.

PLATE LVIII.

HANGING-WALL BRECCIA, FROM A PHOTOGRAPH.

This specimen, from the 1,800-foot level, illustrates the rather rare slate breccia found overlying some parts of the hanging-wall ore bodies. The light fragments are altered hornstones of a warm pinkish-gray tinge. Their banding is in part due to original sedimentation, and in part to secondary films of silica. The darker pieces are thoroughly pyritized. The light fragments contain considerable pyrite as a very fine dust scattered through the rocks. The arrangement of the fragments is without definite order, but adjacent pieces fit each other closely and show a movement from the bottom toward the top of the specimen. The interspaces are in part filled with gray crystalline quartz carrying pyrite and scattered grains of galena. The larger spaces between the fragments are only partly filled and show open cavities lined with projecting crystals of limpid quartz. There is also some dense cryptocrystalline quartz, which is evidently the replacement material formed by metasomatic interchange with the hornstone fragments. The galena grains, which are black in the illustration, lie in the comb quartz and are surrounded by a thin pellicle or shell of pyrite. The pyrite is determined as such by its crystalline faces. It occurs of several generations, the latest form being found on the quartz crystals lining the vugs. The specimen shows no blende, in this respect differing from material from the breccias formed of limestone fragments. Post-mineral shattering is indicated by a little veinlet of quartz which faults the shale fragments and the ore, as may be seen on the right-hand side of the specimen.



SPECIMEN OF HANGING-WALL BRECCIA WITH PYRITIC MATRIX.

slate wall is generally smooth and regular, being commonly unbroken away from the ore bodies. Above the ore bodies, however, it is frequently shaly, and gives every indication of sheeting and movement along the contact point between the slate and dolomite. (See Pl. L, *B*.) At such places it shows either a platy or a fissile parting, or more rarely a brecciation of the slate, a low-grade ore usually cementing the fragments together into a firm breccia. Instances of this were observed in the 2,200-foot level, where the roof is irregular and broken near the ore body and the ore extended 4 to 6 feet into the slate. A similar breccia was also seen near the top of the 1,850 stope, in which the fragments of shale are surrounded by a shell of fine-grained tetrahedrite, and this in turn by quartz, cementing the fragments. These minerals incrust the hanging-wall hornstone and do not penetrate it, there being no evidence of either impregnation or replacement. The workings of the 1,850 south stope show in places this hornstone breccia so softened as to be almost cheesy in consistency for a depth of a foot or more. All observations here show that the crushing is the result of the folding of the strata and the slipping and brecciation that accompanied it. Exposures in the same level (1,850 foot) north of the shaft also show evidence of a strike fault, which in this case is marked by clay selvages, and by quartz streaks. The hornstone fragments show a rude orientation, but it is clear that they formed a breccia whose open spaces are now seen filled by comb quartz and ore, as shown in the specimen illustrated in Pl. LVIII.

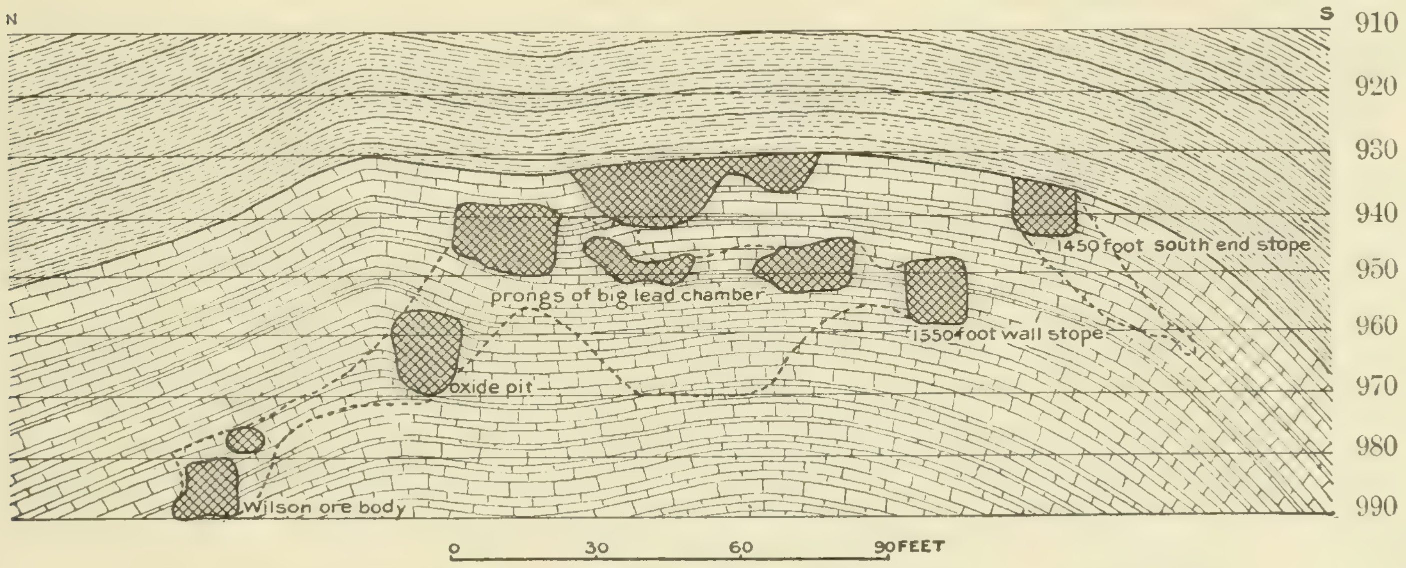


FIG. 74.—Sketch of south ore body of the Elkhorn mine on the 1450-foot level.

North ore shoot.—This ore body is much smaller than that south of the shaft. In the upper levels it is connected by a continuous mass of oxidized quartz ore with the south ore shoot, forming in fact but one ore body, but in depth it has a westerly pitch and is farther and farther away from the other ore shoot. In the upper levels the ore shoot is seen to terminate abruptly to the north against a flexure of the slate, which is particularly well shown on the 650 level. In general, however, the levels have not been extended north of the ore shoot. Followed downward the shoot bifurcates at the 950 level, the southern leg or branch rapidly pinching to a narrow pipe of low-grade ore. The main or northern branch continues downward, but also contracts in size and becomes low grade in character, but expands again between the 1,350 and 1,450 levels into a chamber-like body of lead ore. The shoot is continuous and maintains its general direction of dip and pitch to a depth of 1,650 feet, measured on the slope, where it makes an abrupt turn, pitching to the southeast. This lower part of the shoot is, however, of small cross section and the ore is extremely low in silver, so that the ore body has not been stoped below the 1,750 level. Where it crosses the shaft, about 80 feet below the level just mentioned, the shoot is 3¼ feet wide, and a few tons of ore taken out in sinking the shaft averaged 50 ounces in silver per ton. The indications point to connection between this and the 2,200 ore body shown on the map (Pl. LVII). The latter continues down to a point 25 feet below the 2,200 level, where it suddenly changes to a small mass of low-grade quartz, which, where it was cut on the 2,300 level, was but 2 feet thick and 5 feet long, and carried only a peppering of ore minerals.

South ore shoot.—This remarkable ore shoot has yielded fully two-thirds of the total product of the mine. In the upper levels it connects with the north shoot, as already noted, but assumes its individual character below the 650 level. Like the north ore shoot, it terminates against a flexure of the strata, which is most marked on the south side. A bend in the slate marks its northern limit, also, though this flexure is wanting in the upper levels, where the two shoots connect.

The south ore shoot is a continuous trunk channel from the surface down to a depth of 1,450 feet, measured on the incline, and throughout this length maintains its uniformity of cross section and dip. Below the 1,450 level the shoot varies in character and becomes smaller, but is continuously traceable and workable down to the 2,200 level. The thickness of the shoot varies from a few feet in the uppermost workings, where it will average a thickness of perhaps 8 feet of quartz, to 40 feet in the 1,350 stope. These variations are well shown in the cross section *B* of Pl. LIV.

As a rule the top of the ore body lies against the slate bedding plane. This is well shown in the cross section just mentioned, as well as in those given in figs. 73, 74, and 75. It will be seen from the section that this bedding plane, which forms the hanging wall of the ore body, shows undulations in dip, and that *the ore body is thickest beneath slight arches of the slate.* The significance of this association is mentioned later in discussing the manner of formation of the ore bodies.

The cross section (Pl. LIV, *B*) shows that the ore shoot leaves the slate between the 1,450 and 1,550 levels of the mine, but there is also a connection along the slate contact away from the plane of the section. Like the northern ore shoot, this one pinches up in one place (below the 1,650 level) and is but 8 feet in greatest diameter, but widens out below into a relatively broad mass 6 feet thick. Below the 1,850 level the ore is cut off against a slight fault in the hanging-wall slate, a branch of the ore body which was too low grade and too zincky to work, passing off to the north and into a low-grade mass of pyritic ore and nearly barren quartz. The floor or foot-wall side of the ore shoot, though less regular than the roof or hanging wall, is fairly uniform, and where the ore body is thickest corresponds to the position of a ½-inch to 2-inch argillaceous parting or bedding plane, seen in the dolomite in the foot-wall crosscuts of the mine to be of very constant occurrence.

Intermediate ore bodies.—An extension of the connected ore shoots runs a short distance downward as an intermediate ore shoot, but plays out and disappears in depth. Below the 1,750 level there is another intermediate ore body, which yielded a considerable amount of ore and which is interesting, since at this depth the ore is not oxidized and its original character may be observed. The shoot lies against the slate for the most part, but in some places is like the lower part of the south shoot, separated from the slate by a shell of dolomite. This ore body is probably formed by the coming together of the foot-wall ore shoot (marked Wilson shoot on the map) and the deflected north ore shoot which crosses the shaft below the 1,750 level. This ore shoot, as previously noted, plays out below the 2,200 level, and passes into a pipe of nearly barren quartz 2 feet thick and 5 feet long.

General character of the ore of the main ore shoots.—These great ore shoots are composed of essentially quartzose ore. The quartz, when not altered by the oxidation of the metallic sulphide in it, is usually light gray, clear or glassy, and of rather medium coarseness of crystallization; but dark-bluish, very dense, cryptocrystalline silica also occurs. As described later, there is a very marked and constant association of quartzose milling ore when the ore body lies against the slate, and of silver-lead smelting ore where the ore body lies wholly in the dolomite. This distinction is not invariable, considerable masses of quartzose ore having been found in the foot-wall ore bodies, and of galena or its decomposition products in the hanging-wall ore bodies, but the statement is true in a general way.

The ore bodies consist essentially of nearly solid quartz, mostly free from included masses of limestone or of slate. Exceptions to this occur in the 1,750 stopes, where the quartz cements limestone fragments and where the slate is brecciated and the fragments are cemented by ore. The first is less common than one would suppose. The specimen Pl. LX, *A* shows an example of this, and the slate breccia is shown in Pl. LVIII. While the mine was producing heavily only the good ore was extracted, and much low-grade ore was left in place which could have been mined at a profit before the depreciation of silver, but could not pay the cost of extraction during the last three years previous to the closing down of the property. For this reason the extent of these low-grade portions of the ore shoots and their possible connection downward through the dolomite is uncertain. The quartz ore of the hanging-wall ore shoots was more or less oxidized and free milling down to the 1,350-foot level. Below this point it steadily increased in baseness, owing to the presence of galena and tetrahedrite. In the upper parts of the ore body these minerals have been partly altered and leached out from the ore. "It is of interest to note, as the rule," says Mr. Kelley, "that the actual value of the ore itself did not diminish as depth was obtained and that the ore contains as much or more silver than that which was found at higher levels, although it was associated with a larger proportion of base metal."

Oxidation extended deeper along the hanging-wall bodies than in the foot-wall lead chambers, as the solutions naturally traveled down the slate contact. Even on the 2,300-foot level the freshly cut quartz bodies show yellow litharge spots about galena grains, and green staining of copper carbonate about particles of tetrahedrite. The pyrite is rusty and the quartz is porous about the minerals just noted. This alteration was not on a large scale, as it was in the upper levels, but it clearly shows that oxidizing waters penetrated to this depth. The ore bodies above consist mainly of oxidized ores carrying some pyrite, occasionally residual nuclei of galena, but show no definable silver minerals. These ores change in depth to those in which tetrahedrite appears, and this is undoubtedly the mineral from which the silver values have been derived in the upper part of the ore bodies. As a rule the ore shows no well-defined structure, but consists of interlocking grains without banding or crustification. Rarely there is a banding due to the replacement of limestone fragments by dark-colored jaspery quartz, the intervening space being filled with white quartz, so that the darker-colored variety is in strong contrast to it. Other notes on these characters are presented in another chapter, where the evidence showing that the ore was deposited as a replacement of dolomite is fully given. In one place where pyritic ore occurs lying against the slate the ore shows a well-marked banding parallel to the bedding plane of the slate.

In the 1,750 stopes galena was found in the quartz lying against the slate, but as a rule where galena occurs it is confined to the dolomite and is not found in quartz.

ISOLATED ORE BODIES IN THE DOLOMITE OR FOOT-WALL LEAD CHAMBERS.

Occurrence.—Besides the well-defined and continuous ore shoots of the mine which have just been described, there were a number of detached ore bodies of highly argentiferous lead ore lying encased in the dolomite. As these ore bodies occurred in the foot-wall rock and were usually separated from the slate by a greater or less thickness of dolomite, they were not developed by the mine levels run along the slate bedding plane. In general they occur close to the main ore shoot, and with one exception are found above the 2-inch argillaceous band in the dolomite, which has been called the foot wall of the ore deposit. These ore bodies are shown on the map of the mine workings by a distinctive color, but it is difficult to separate them from the hanging-wall deposit, as they often lie in the dolomite directly beneath the main ore shoot and frequently connect with these shoots. The foot-wall crosscuts and drifts of the mine are also designated on the map by separate pattern, and their irregularity is due to the fact that the prospecting for the foot-wall bodies was very largely a matter of luck and not of system. The relation of the foot-wall bodies to the main ore channels is best understood by reference to the cross sections shown on Pl. LIV and figs. 73, 74, and 75. The vertical sections do not show the true foot-wall chambers, though they do show that the main shoots become foot-wall bodies; that is to say, they are separated from the slate by a greater or less thickness of dolomite, and when this occurs there is a corresponding change in the mineralogic character of the ore. The sections shown in the figure indicated that these bodies occur beneath the main ore channels or alongside them; that they are found in the same fold or pitching arch as the ore shoots, and that, insignificant as the connecting feeder or stringer of ore sometimes appears to be, they really are a part of the same general ore mass and owe their isolation to the presence of favorable physical conditions, such as crushing of the dolomite, or to those vagaries of solutions dissolving in the limestone which are apparent on the maps of underground caverns. The difference in mineralogic character is believed to be due to a selective reaction by the dolomite, whereby lead-silver ores are deposited when ore channels penetrate limestone, and is in accord with observations of ore deposits the world over.

When the ore is removed from these bodies great spaces are left which might readily suggest that they represent cavern deposits, but this name is misleading, as it implies an origin by cavern filling either partial or complete. Projecting fingers of the deposit form short pipes of ore, but although water courses exist in the dolomite and are often traceable for hundreds of feet, no such pipe of lead ore exists in the mine, and this is of itself evidence that the ore bodies originate by replacement. The form of the ore bodies is very irregular; they commonly show rounded sides with projecting points and fingers, and such projections are more apt to mark the upward extension of the ore body along the dip than either its downward or its lateral limits.

In general these foot-wall bodies are extremely irregular. There seems to be a tendency for them to be limited by the so-called foot wall, which is a thin seam of argillaceous limestone from ¼ inch to 2 inches in thickness, occurring at a distance of about 35 to 50 feet from the hanging wall. This occurrence is shown in the vertical cross sections represented on Pl. LIV, *A* and *B*, and in the sections across the ore shoots shown on figs. 73, 74, and 75. The significance of this foot wall lies in the fact that, owing to its argillaceous character, it would limit replacement of the limestone and therefore form a somewhat regular foot wall to these lead chambers. The roof of the foot-wall bodies is irregular, and no definite limit has been found. In the dolomite, prongs and fingers extend out from the main body in various directions, giving an extremely irregular profile when they are seen in cross

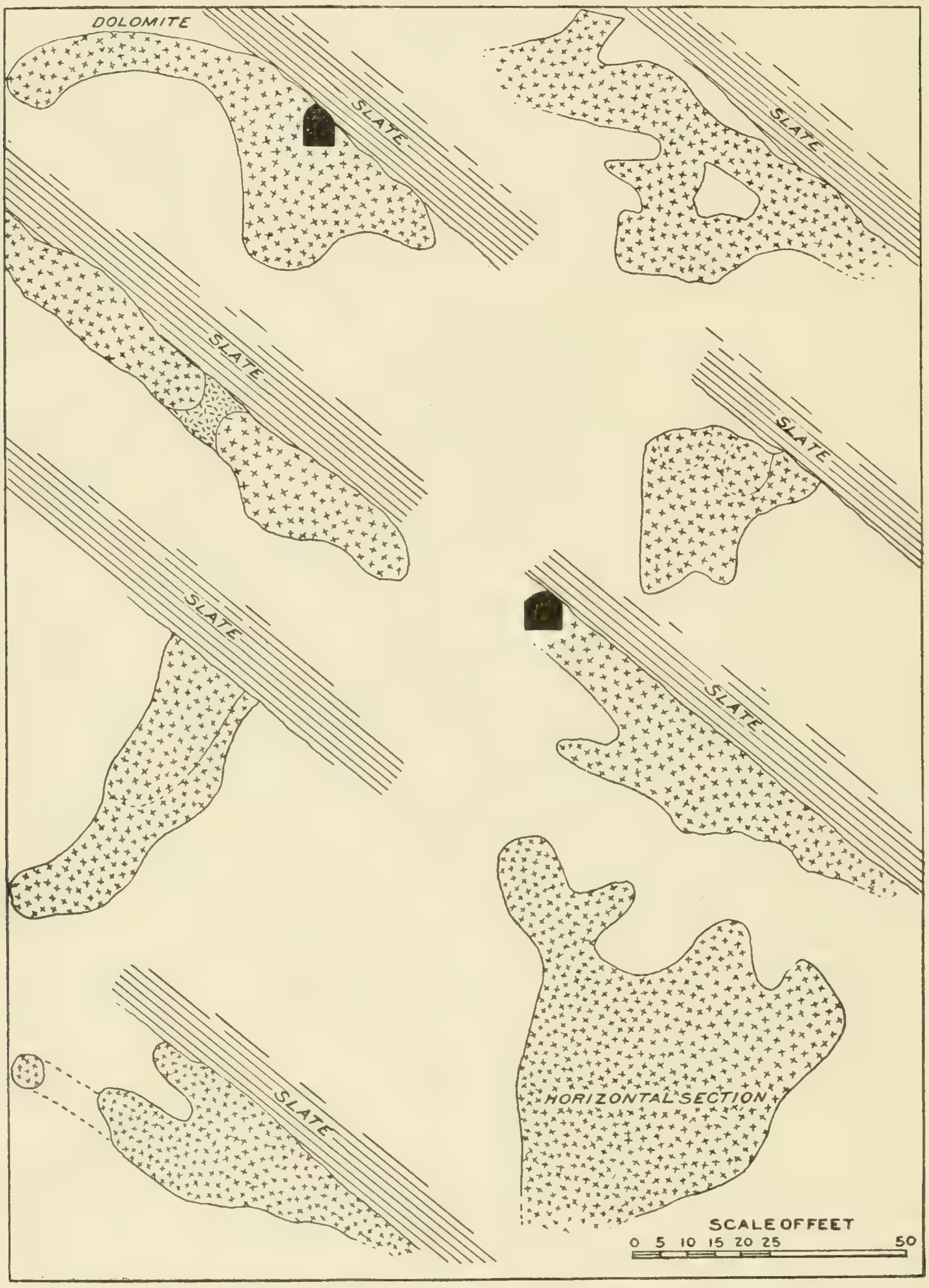


FIG. 75.—Section across the 2,200 ore body of the Elkhorn mine, showing typical forms of replacement deposit.

PLATE LIX.

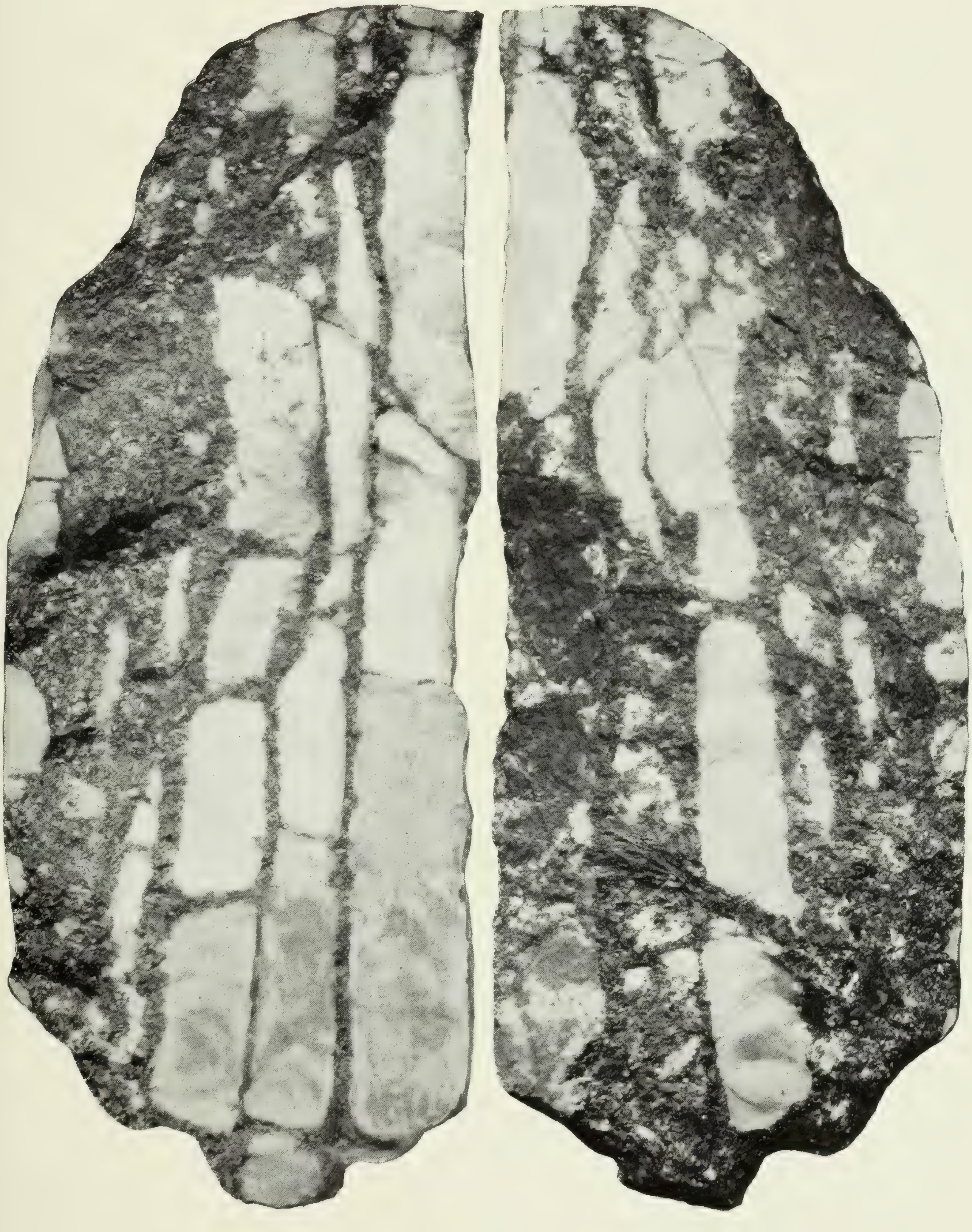
PLATE LIX.

SLAB OF ORE FROM THE WILSON SHOOT.

This plate shows photographs, on a reduced scale, of both sides of a slab of ore from the Wilson ore shoot. The white areas are the white dolomite sand rock and the dark areas are ore consisting of galena, yellow blende, and a very little pyrite.

A shows the dolomite fractured into slabs by parallel planes and the slabs broken into rectangular blocks by cross fractures, which, as a rule, do not extend through more than one slab. In the lower part of the specimen replacement has gone far enough to obliterate the rocks, and only nucleal masses of limestone are seen. In the upper part the fractures contain galena and blende, which has penetrated along the minutest cracks and by replacement has enlarged the opening and formed the layers seen.

B shows the reversed side of the same specimen, which is a slab about an inch thick. In this specimen the lower blocks of white dolomite which are so conspicuous on the first figure are almost completely replaced. The specimen shows that little cracks extend into the blocks of white dolomite, and that replacement takes place rapidly in the interior of the mass and not alone from the outside, so that while the corners are rounded and progressive replacement is shown along the borders the interior is attacked until only a sponge is left of the white dolomite.



GALENA ORE, SHOWING LIMESTONE BRECCIA CEMENTED BY ORE

section. The sections shown in Pl. LIV are typical for these foot-wall bodies, though they actually represent the 2,200-level hanging-wall ore shoot. These foot-wall bodies invariably show a connection at some point with the main ore-body ore channels. These connections are strings of galena ore passing into a mixture of galena and quartz, and this into purely quartz ore connecting with the hanging-wall quartz body.

Filling.—The ore forming these lead chambers is not a solid mass of galena or its alteration products, but consists of a breccia of white or yellow dolomite fragments cemented by ore (Pl. LIX). Sometimes the upper part is a limestone breccia with the interspaces filled with blue quartz, in which case the quartz carries from 50 to 100 ounces of silver, though it may show no recognizable minerals. Such ore carries no lead, but when broken down is low grade and will run but 15 ounces of silver per ton. In the upper lead chambers the higher parts of the ore bodies were oxidized to lead carbonates, showing a slight coloration from copper carbonates. Very often, also, there was a quartz crust found as a shell about certain parts of the ore body, usually near the top. In general, however, the lead ores are limited abruptly by limestone, or by low-grade ore from which strings and fingers of the galena and zinc extend out into cracks of the white limestone. No foot-wall bodies have ever been found in the mine above the 550-foot level.

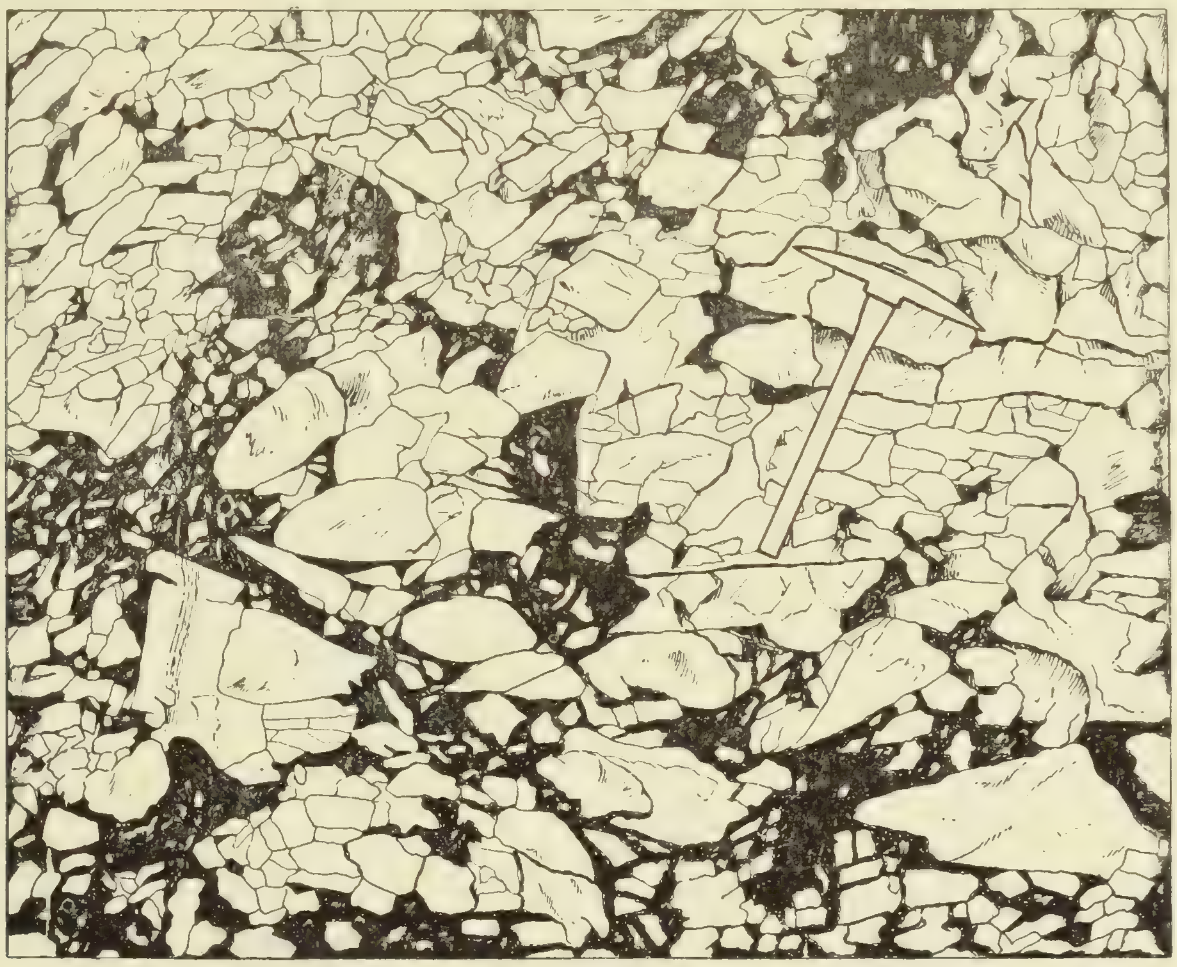
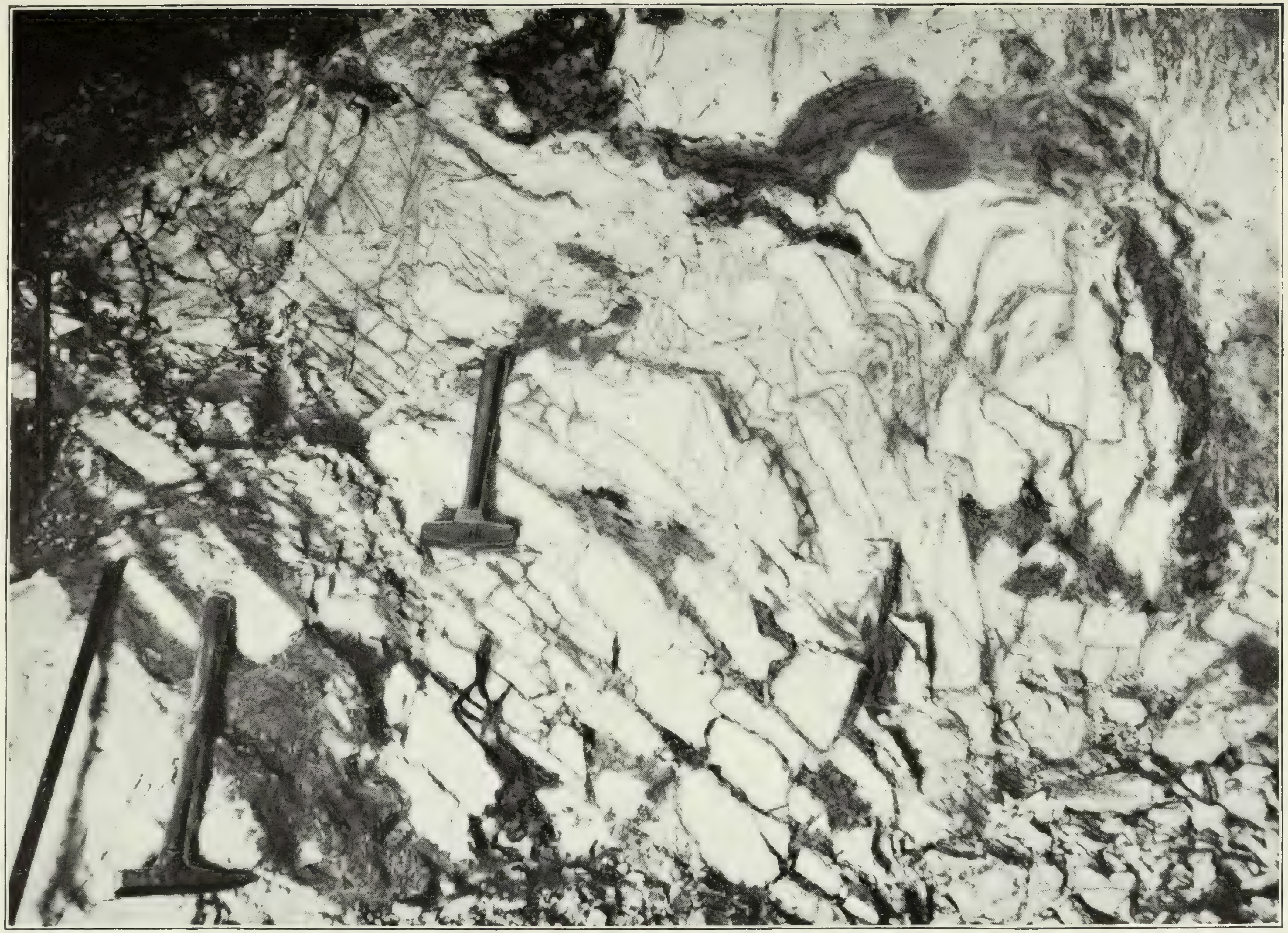


FIG. 76.—Face of Wilson ore body, 1,450-foot level stopes of Elkhorn mine.

An exposure showing the typical character of the filling of these foot-wall chambers is shown in Pl. LX, made from a flash-light photograph taken by Mr. C. F. Pearis. The actual face illustrated was in the 1,750-level intermediate stope. The view shows that the limestone blocks are in part angular and in part rounded, and though positive proof that the ore is formed by the replacement of limestone is afforded by underground workings, by numerous specimens, and by thin sections of the ore seen under the microscope, part of the ore body appears to be due to the filling of the open spaces between the limestone fragments. Any marked solvent action would have rounded off the sharp angles and destroyed the long, thin slivers of limestone which are shown in the picture. Another face shown in fig. 76 which is a direct reproduction of another flash-light photograph taken by Mr. Pearis, shows broken limestone which in the lower part of the view is a breccia and in the upper part has been flexed and crushed sufficiently for the solutions to penetrate along the fractures, cementing the pieces together. There is evidence in the arrangement of the limestone blocks, not only of the tearing apart of the limestone in parallel plates, but also of movement along the fractures by which these blocks are twisted and their orientation destroyed.

Description of a foot-wall ore body.—Most of the foot-wall bodies were practically mined out at the time of the writer's visit, the ore that was left being found along the sides of the ore bodies or in small projecting prongs of the main chambers. A good opportunity for an examination of an ore body of this kind was, however, afforded by the opening up and extraction of an ore body lying between the two main ore shoots. This ore body has been called the Wilson shoot, and lies in the dolomite between the south ore shoot and the main shaft. This body, unlike foot-wall bodies in general, is not directly behind or underneath the main ore shoot, but lies off to one side and at a greater distance from the slate contact than most of the foot-wall bodies. Its general characters, however, are similar, though it contains a larger proportion of quartzose ore. The ore body begins as a spur of the main south ore shoot near the 1,250-foot level. This spur passes off into the foot-wall dolomite as a pipe or chimney and opens out into a broad and high chamber, from which large amounts of ore were extracted. It forms a continuous, though irregular, ore body from a point below the 1,250-foot level to a short distance below the 1,650 level; its farther extension is uncertain, as the ore at that point was too base to mine, though it lies directly over the upper part of another ore body and probably connects with it by low-grade ore. Its location corresponds to a decided bend in the strata, which develops into small cross faults throwing the slate hanging wall in the 650 and lower levels. These faults are apparent in the slate, but are dissipated in the limestone in a series of parallel fractures or in a simple crushing of the rock. The connection with the main south ore shoot shows porous and oxidized quartz, which changes in the limestone to oxidized lead ore consisting of cerussite and other products of decomposition carrying high values in silver. This character of ore continues



ORE BRECCIA, 1,650-FOOT SOUTH FOOT WALL ORE BODY (LEAD CHAMBER), IN DOLOMITE.

Looking south toward foot walls. The white areas are blocks of unreplaced dolomite. The dark areas represent ore (galena, etc.) filling cracks between fragments and replacing them. From flash-light photograph taken by C. F. Pearis.

downward to the 1,400-foot level, the silver contents being very uniform except on the borders of the deposit, where it becomes lower in grade. This decomposed ore contained nucleal masses of sulphides in the upper part and changes to a solid body of galena with blende and pyrite about 200 feet below the top. The sulphide ore continued downward, but decreased gradually in silver contents, corresponding to a decrease in amount of galena and a larger amount of zinc and pyrite, until finally, at a point 10 to 15 feet below the 650 level, the ore consisted largely of black-jack (blende) with iron pyrite, and carried from 10 to 15 ounces of silver per ton. The big ore chamber consisted mainly of shipping ore of the character just noted, the upper 6 feet, however, being a rich oxide ore that was taken off for milling, and rich bunches and streaks of this ore were found along fracture planes extending into the limestone above the ore body. Oxidation had also extended a short distance down the sides of the ore body, altering the outer portion of the ore and the limestone adjacent to it. The top of the main chamber of the shoot differed somewhat from this in showing a clean roof of white dolomite sand-rock devoid of any rust, stain, or other evidence of oxidation, and the quartz found near the top of the ore body was white and vitreous. In the north prong of this big chamber there was some oxidation, the dolomite being yellow with dendritic manganese markings and the quartz carrying some oxides.

The rich oxide ore, which, as just noted, was taken off for milling, lay against the roof of the ore body and rested upon the shipping ore of the foot-wall side. The quartz was brown and watery looking, and apparently carried no values, though it assayed 75 ounces in silver and formed a very good milling ore. Underneath the altered lead ores there was usually more or less sulphide ore, which averaged over 200 ounces in silver per ton. The pyritic ore, into which the ore shoot passed in depth, varied greatly in value. This no doubt depended somewhat upon the proportion of galena which it contained, but also consisted in a variation in the silver contents of the pyrite itself. The size of these foot-wall workings is often somewhat larger than that of the actual ore body, since strings of rich galena extend out into the limestone, particularly where the ore body wedges out at the sides and ends. This is well shown in the lower end of the 1,650 foot-wall stope, where the ore body is 4 feet high in the lower part, with vertical side walls showing no stringers of ore running into them. At the lower end, where the ore ends in a pocket, the limestone overlying it shows streaks and films running out into the yellow dolomite forming the roof. Commonly the yellow color of the dolomite is an indication of the proximity of ore bodies, as it is due to oxidation following down the borders of the ore shoots, and it is said to have marked the occurrence of the richest galena. As an exception to this, it should be noted that in the 2,200 stopes the ore found in the white limestone and associated with the white quartz was the richest ore. This, however, is explained by the occurrence of tetrahedrite in the ore. In general it may be stated that in all the ore bodies the proportion of pyrite increases in the lower part, and in some cases the low values of this pyrite prevented a thorough exploration of the ore body, so that its actual limits and lower extensions are not definitely known. However, fairly thorough prospecting on the 2,300 south levels has demonstrated that the ore bodies have pinched out at that depth and that no large masses of payable ore occur.

Considerable space has been devoted to a description of the foot-wall bodies, as it is believed that they are merely parts of the main ore shoots and show in the structure evidence of the manner of formation of the deposit. In the lead chambers the limestone has been replaced mainly by galena; in the main ore shoots, by quartz carrying tetrahedrite.

NATURE OF THE ORE DEPOSIT.

STRUCTURAL RELATIONS OF THE ORE SHOOTS.

An examination of the mine map shows a very interesting connection between the occurrence of the ore shoots and the presence of flexures in the strata. With rare exceptions the mine levels are driven along the slate-limestone contact. The map therefore shows horizontal sections of the contact planes, and the curves in the levels correspond to flexures in the rocks. It is apparent from the mine map that the strata are bent by two flexures whose arc is longest in the deeper levels. The flexures are farthest apart in the deep levels and approach each other in the upper levels, until they form practically one fold. The diagram (fig. 77) which is made from the mine map, shows that the ore occurs on the under side of steeply pitching arches; that is, underneath flexures in the hanging-wall slate. This may be regarded as definite proof that the ore-bearing solutions came from below and followed up channels formed by the crushed limestone and confined by the impervious hanging-wall slate. This proof is the more interesting because of the gradual impoverishment of the ore shoots in depth and their pinching out in the deeper workings. The material for the ore shoots must have come through fissures now filled with low-grade or barren quartz, such as the small ore shoot of the 2,300 level. The ore of the hanging-wall bodies was in part a breccia and in part a solid ore. It is certain, however, from the occurrence of the

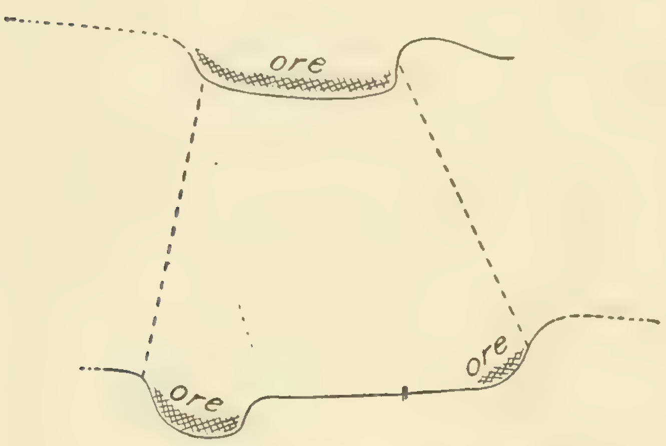


FIG. 77.—Diagram showing occurrence of ore shoots in pitching arches or folds of the strata, Elkhorn mine.

ore shoots that ore deposition was practically controlled by the rock flexures, and the ore bodies are thickest where undulations in the slate occur, as shown in the vertical cross sections. In a lesser degree the minor fractures also affect ore deposition.

In order to show the relation of the ore bodies to the folding of the rocks a section has been prepared across the ore bodies of the 1,450 level. The plane of the section is not a horizontal one, but has been made perpendicular to the hanging wall in order to give a true cross section of the ore body. The figure shows a very marked bend in the hanging-wall slate, and the ore bodies cut are only parts of a very much larger chamber indicated by the dotted lines. A similar section (fig. 73, p. 478) made parallel to the drift and perpendicular to the hanging wall on the 650 level, shows the ore body south of the shaft. In this case the position of the foot-wall bodies relative to the hanging-wall ore shoot is plainly indicated. The plane of the section cutting across projecting arms of the hanging-wall ore body does not show a continuous mass of quartz along the ore contact, although the bodies seen in the figure would show such connection if cut by planes either above or below that actually used. On this figure no attempt has been made to indicate the actual extent of the ore bodies in other planes.

South of the shaft the flexure in whose axis the main ore shoot is found is accompanied by several small cross faults, and these faults have affected ore deposition. On the 1,850-foot level there is undoubted evidence of a strike fault, and the ore is connected with and comes against this fault. In passing down the winze below the 1,850-foot level the strike fault is seen to turn downward and become nearly vertical, and is accompanied by a cutting off of the ore. It looks as if the ore deposition was controlled by the open spaces formed by slipping along a step fault in which the tearing off or projecting corners furnished a breccia which filled in the angles and was the seat of ore deposition. If this theory is correct, ore should be found wherever a fault changes its inclination from vertical to an angle corresponding to that of the hanging wall.

ORE SHOOTS CONSTITUTE SADDLE DEPOSITS.

The Elkhorn ore bodies are saddle deposits formed in pitching arches beneath a bed of impervious slate and in a dolomite marble. Lying along the bedding plane between the dolomite and slate, it would commonly be called a "contact deposit," but, as pointed out by Emmons,[1] this is a term that should properly be confined to the contact between igneous and sedimentary rocks—that is, between rocks not of contemporaneous origin. The term "bedding-plane deposits," though somewhat clumsy, is preferable to "bedded vein," since the latter seems to imply horizontality and possibly synchronous formation with that of the inclosing strata. In the disturbed strata of the Elkhorn district the folding has been accompanied by movement or slipping along the bedding planes, and this movement has produced brecciation and minor faulting along the axes of the lesser folds. The impervious slate acts as a cover that confined the circulating waters to the pipes of crushed rock in the saddle of the arches. Similar contact deposits between slate and limestone are relatively common in the Rocky Mountains, and may be ascribed to the impervious and insoluble nature of the slates and perhaps to the fact that precipitation was induced by the retardation of the current along the confining wall. As already stated, it is only when the slate is brecciated that ore deposition has taken place in this rock, the deposits generally being confined to the dolomite.

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[1] Structural relations of ore deposits: Trans. Am. Inst. Min. Eng., Feb., 1888, pp. 10, 14.

That actual movement has occurred along the slate and limestone bedding plane is proved by the platy nature of the strata at their contact, as well as by the brecciation of both slate and limestone in the folds. That this movement was not general, and hence that the bedding plane was not the site of a strike fault or fissure, is shown by the localization of the brecciated material and of the slips coincident with the folds. On the other hand, the ore channels occur in the saddles of the folds, and it is evident that folds formed under a relatively light load would tend to develop open spaces in the saddles. Where a soft stratum, such as shale, occurs between hard bodies there is a tendency for the soft rock to flow into and fill such a cavity, forming a saddle-shaped mass, thick on top of the fold and very thin on the shanks. In the Elkhorn deposits, however, the hornstone (called slate by miners) yielded to flexure and formed a generally unbroken, impervious roof; though metamorphosed, it resisted crushing better than the underlying brittle and friable dolomite, so that the latter was crushed and shattered and formed a loose breccia under the arches. As the general rock folding of the sedimentary strata occurred before the igneous rocks were intruded, and hence before rock metamorphism took place, it is necessary to suppose a later period or periods of folding in which the convolutions in which the ore deposits occurred are supposed to be due to the thrust of the later igneous intrusions.

In its brecciated character the deposit is analogous to the silver-lead deposits of Eureka, Nev. Interstices between the fragments of crushed limestone would admit of a relatively free passage of surrounding waters, and would furnish space for the precipitation of quartz and the ore minerals, while the readily soluble dolomite fragments would be replaced by vein material. The irregular forms of such ore bodies are to be explained by the occurrence of crushed masses of rock and by the dissolving action of the mineralizing solutions.

The Elkhorn deposit is noteworthy for several reasons:

First. It occurs in plicated sedimentary rocks metamorphosed by a succession of igneous intrusions.

Second. It occurs in the crushed rock found in the saddle of minor folds, and follows the bedding plane of an overlying altered shale (hornstone). The crushed rock formed the primary ore channel for uprising siliceous waters.

Third. The deposits are not the result of the filling of preexisting caves in the limestone, but are mainly due to gradual replacement of dolomite by the substances brought in by ore-bearing solutions. The ore is confined almost entirely to the more readily soluble dolomite, when found in the hornstone being only a cementing material for fragments of that rock.

Fourth. The ore is believed to be derived from below, because it occurs on the underside of an impervious stratum, bent in pitching anticlinal folds.

Fifth. That the ore decreases in amount and richness in depth is no objection to the theory proposed, since it is now well known that in the Black Hills the barren, or but slightly mineralized, "verticals" (mere cracks traversing the rock) are the feeding channels for important ore bodies that occur in readily replaceable rocks, particularly at bedding-plane contacts with adjacent impermeable strata.

ALTERATION OF COUNTRY ROCK.

The rock adjacent to the ore deposits shows none of that marked alteration characteristic of ore deposits in igneous rocks. The dolomite is not the result of the dolomitization of a limestone by solutions ascending through the ore channels, since it maintains its character remote from the ore. The hanging-wall slate is usually slightly altered for a few inches from the ore bodies, and where the rock is brecciated and the fragments are cemented by metallic sulphides the rock has been decomposed and even pyritized. The dolomite does not show alteration from the ore-depositing solutions. This is lacking because the action was one of replacement of dolomite by silica and sulphides. In this sense the rock is altered, for near the ore bodies it is shattered or crackled and the fractures are filled by silica. These silica films are due primarily to a penetration of the solution along the fractures, but they are more properly replacement deposits, since their sections studied under the microscope show that the dolomite is attacked along cleavage lines, etching and deposition of silica going on simultaneously. This is, of course, merely a phase of the process of ore deposition, for the quartz films often carry sulphides, and if the dolomite be dissolved away by dilute acid a skeleton is left, composed of silica and metallic sulphides, which constitutes a cellular mass pseudomorphic after the dissolved fragments. Where oxidation of the sulphides has produced acid waters this same action has taken place in nature. Where substitution has gone still further, and the original solutions have replaced a large proportion of the limestone, the original brecciated character is lost, and a mass of quartz, or ore, carrying included fragments of limestone is all that is left to indicate that the process was one of replacement.

MODE OF FORMATION OF ORES.

ORIGIN BY REPLACEMENT.

That the ores are deposited from aqueous solutions there can be no doubt; their general occurrence, mineralogic character, and a study under the microscope of thin sections all confirm this conclusion, and as such origin is now generally accepted for most ore deposits no further comment need be made on this subject. That the ores were deposited by ascending waters is proved, as has already been stated, by their occurrence under pitching arches. That the ores are deposited by replacement of country rock, and only to a minor degree by the filling of the interspaces between limestone fragments, is proved by the evidence afforded by a study of the ore deposits, by the ores themselves as seen in hand specimens, and by thin sections examined under the microscope. By replacement is meant what is technically called metasomatism; that is, interchange of substance. It differs from pseudomorphism, as the latter implies preservation of the form of the matter replaced, while metasomatism does not involve the preservation of either form or substance.

The positive evidence of metasomatism is very striking and complete at Elkhorn. In the foot-wall ore bodies especially, the structures—which are represented in the plates made from photographs of actual ore faces—show that masses of crushed dolomite resulted from folding, and the open space between the fragments, if such existed, would, if filled by ore, produce the ore breccia now seen. A careful study of all the cavities left by the extraction of ore showed that no preexisting caves served as loci for ore deposition. Moreover, the ore bodies as mined never showed open cavities above the ore. Hand specimens, as for instance the one of which photographs are reproduced in Pl. LXI, show little dolomite blocks in various stages of replacement. In the quartz ores every stage may be seen, from little films of silica penetrating the shattered limestone along capillary fractures to a mass of quartz containing nuclei of limestone. It should be noted also that the ore shows no crustification.

The dolomite adjacent to the ore bodies is netted with films of silica which are often extremely thin. The silica occupies fissures which are evidently the result of a shattering of the rocks in place, without disturbance of the fragments. Where the silica carries no metallic

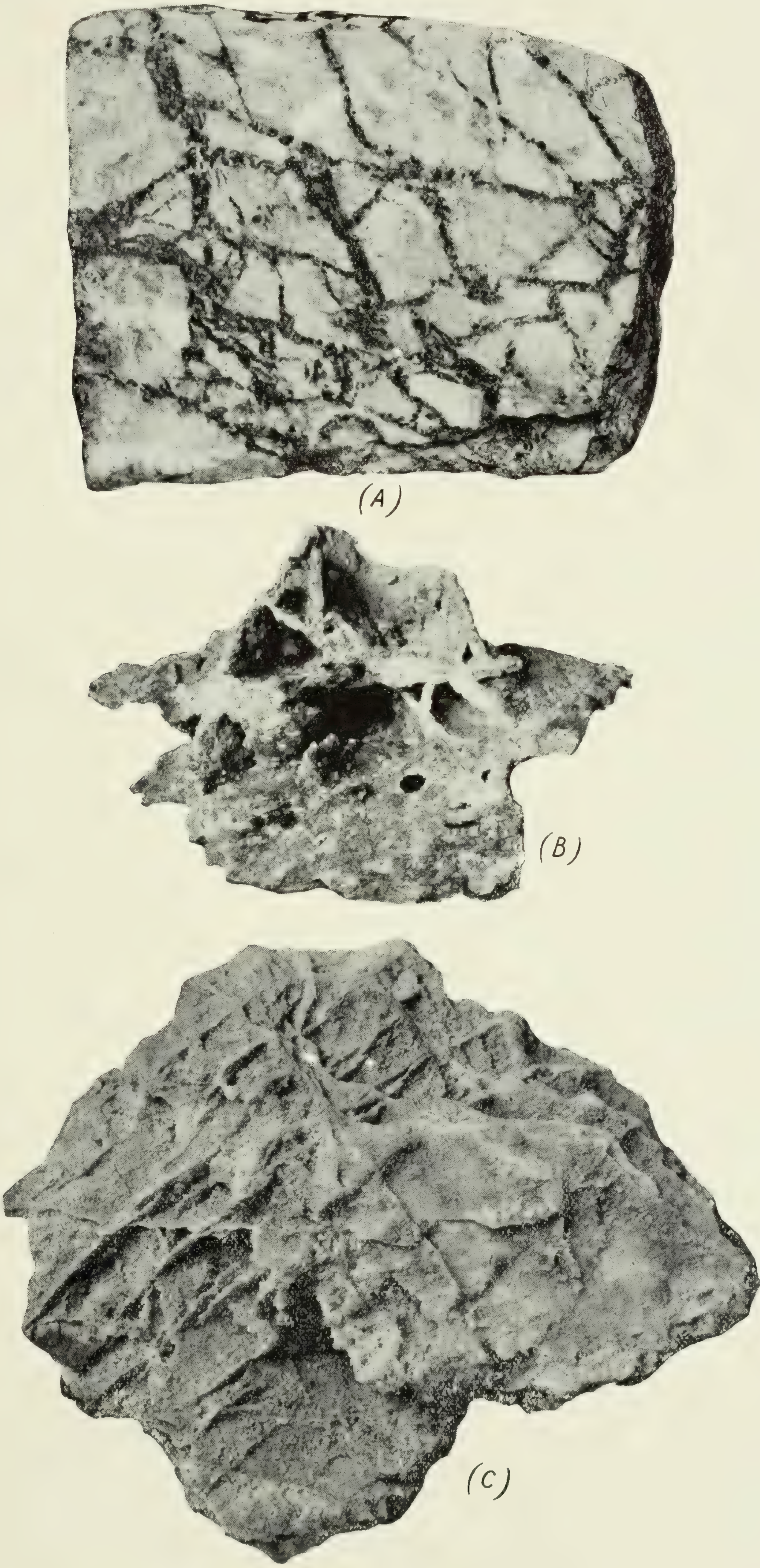
PLATE LXI.

PLATE LXI.

LIMESTONE FRAGMENTS CEMENTED BY QUARTZ.

The photograph shows a specimen (*A*), natural size, of limestone fragments cemented by dark-blue quartz. The fragments fit together so closely that it is evident that no movement has taken place, but that the brecciation is the result of a shattering of the rock with the infiltration of siliceous waters and replacement along the cracks. The quartz carries good silver values, though the ore particles are too minute for determination of species. The quartz is extremely finely granular, showing the texture and color characteristic of metasomatic replacement, and not the comb structure of the filling of open cavities. The specimen illustrates an earlier stage in the formation of the quartzose ore of the hanging-wall ore shoots.

Other specimens (*B* and *C*) show progressive stages in which the small fragments are replaced and the quartz seams are enlarged by the rounding off of corners, and still others in which only residual masses of limestone occur scattered through a massive quartz.



LIMESTONE FRAGMENTS CEMENTED BY QUARTZ.

sulphides it is white and granular, so that the films are scarcely recognizable in the white dolomites, but their presence is perfectly apparent in thin sections studied under the microscope; moreover, the films are sufficiently coherent to show as a skeleton of intersecting plates when the dolomite is dissolved in acid. Where the dolomite is yellowish or rusty from slight oxidation the silica films are marked by rust lines, and are very prominent. Further oxidation results in the dissolving out of the limestone, leaving the silica films forming the walls of a cellular mass. In the oxidized zone these thin plates of silica are frequently coated by clusters of delicate calamine needles. More commonly, however, they are covered by a drusy coating of quartz, and this may so thickly incrust them as finally to fill the cavity. In extreme cases the cavities of this cellular material are completely filled by quartz, but slight differences in color and texture enable one to recognize the original silica film, and the later quartz shows the shape of the former limestone fragments (Pl. LXI). Where this has taken place it is evident they were not the result of direct metasomatic replacement, but rather of the dissolving out of limestone fragments and a subsequent filling of open cavities left by their removal. In the larger quartz seams lying between limestone fragments there is a gathering of the darker silver-rich quartz about the edges of the limestone fragments. This quartz often shows no recognizable minerals, though the lens discloses the presence of black films and sooty-like granules in the interstices between the quartz crystals. Very often the quartz is almost white, but is spotted with grains of tetrahedrite, bournonite, and pyrite. This mineral-bearing quartz is usually in angular masses whose forms suggest the replacement of limestone fragments, and these masses are separated by white comb quartz that is barren. In some instances the replacement material is, however, a jasperoid—dense, horny jasper that shows the cryptocrystalline structure of metasomatic quartz.

Evidence of replacement shown by thin sections of ore.—Thin sections of the ore and of the accompanying dolomite and quartz show a replacement of dolomite by galena, pyrite, and quartz. The replacement by galena is very striking, and minerals penetrated the dolomite in tongues and branches in a very irregular way. Pyrite occurs as veinlets composed of grains strung out along fractures in the dolomite. The fracture is closed and is sometimes apparent only as a cracking of the grains, disclosed when the section is examined under crossed nicols. More often the fracture is filled by very fine angular fragments of the dolomite torn from its walls. The pyrite occurs in this and also in crystals penetrating the crystals of the solid dolomite grains alongside the fracture. In many cases there is no quartz present, but more commonly the dolomite fractures are filled by silica, with or without metallic sulphides. It has been noted that sometimes pyrite grains occur abundantly dotting the dolomite parallel to the fissure wall, and in such cases the quartz carries no pyrite, or else is simply dark colored, owing to a dust of minute particles of the iron sulphide. More commonly the quartz is seen replacing the dolomite, both as well-marked fissures and as grains which are apparently interstitial, presenting the appearance of an open sponge of dolomite filled by quartz. In this case, however, the relation of the crystalline outlines of the quartz to the dolomite grains and the penetration of the latter by the quartz show clearly that the silica has replaced the former mineral. In general the quartz replacing the dolomite shows a finely crystalline character. Oftentimes fragments of the carbonate are surrounded by a band of dense, cryptocrystalline quartz which is of the character supposed to be typical of replacement.[1]

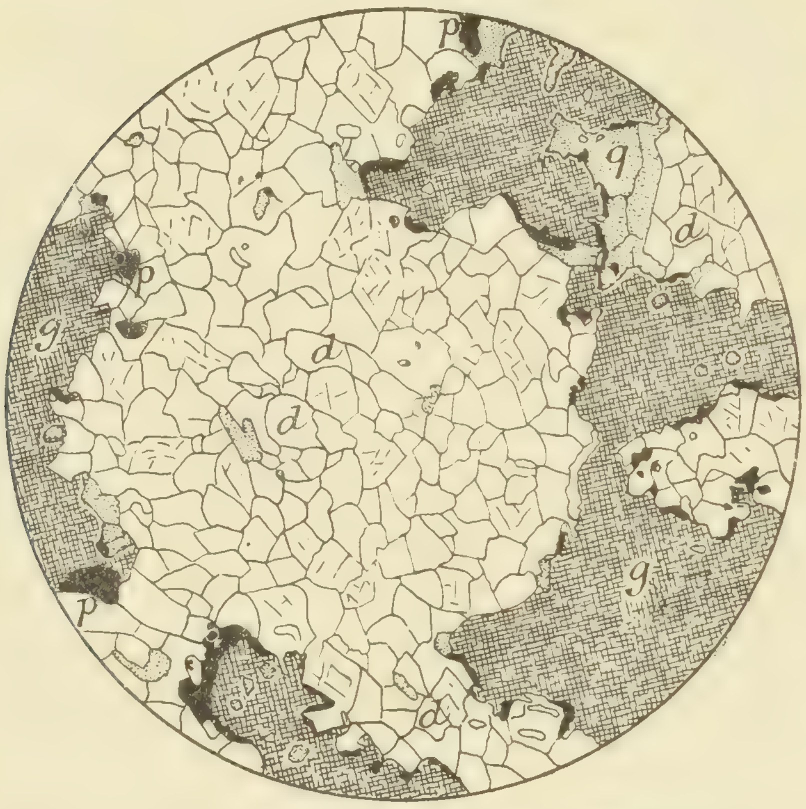


FIG. 78.—Thin section of ore showing replacement of dolomite by galena (after Lindgren). *g*, galena; *p*, pyrite; *d*, dolomite; *q*, quartz, secondary. Magnified 15 diameters.

More often this cryptocrystalline quartz is subordinate in amount or entirely wanting, and the main body of that mineral presents the somewhat coarsely crystalline character which is supposed to be typical of the filling of open spaces. It should be noted, however, that the quartz grains do not exceed a millimeter or two in width, and in no case do they form the very coarse comb quartz seen in many fissure veins. The nearest approach to this structure is seen where quartz crystals partially filled the drusy cavities resulting from the dissolution of limestone fragments.

Attention has already been called to a replacement that is more in the nature of pseudomorphism than that which has just been mentioned. This phenomenon has been described in discussing the character of the ores, and it has been shown that the shattered limestone has been penetrated by solutions which deposited films of silica; that subsequently the limestone has been dissolved away, leaving the silica as the division walls of a very loose cellular material; and, lastly, that secondary waters have deposited silica upon these thin walls until in many cases the cavities have been completely filled by some of the coarse quartz, showing comb structure, while in other cases the open spaces have been but partly filled and show drusy centers. The galena ores of the foot-wall bodies show even better evidence of replacement. The hand specimen, of which a photograph one-half natural size is reproduced in Pl. LIV, shows a limestone sheeted by fractures parallel to the bedding and the resulting slabs broken into rectangular blocks. These blocks are now firmly cemented together by galena ore carrying zinc blende and a little pyrite. The accompanying plate presents a photograph of both sides of the specimen, showing how the dolomite blocks seen on one side are almost entirely replaced on the other. The thin sections of the galena ores show particularly conclusive examples of the replacement of the dolomite. The dolomite rhombs are irregularly penetrated along cleavage planes and to a lesser extent by irregular, sack-shaped cavities, often into their faces, by galena and the accompanying silica. The silica is in part crystalline, but in large part of the cryptocrystalline variety so characteristic of metasomatism. Finally, what might be called negative evidence in favor of replacement also exists in the absence of open caverns, partially filled open spaces, the total absence of crustification, and the fact that the hanging-wall slate was attacked but slightly by the mineralizing solutions.

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[1] Gold-quartz veins of Grass Valley, California, by Waldemar Lindgren: Seventeenth Ann. Rept. U. S. Geol. Survey, Part II, p. 391.

SOURCE OF THE METALLIC CONTENTS OF THE ORES.

The metallic contents of the Elkhorn deposits are believed to have come from the igneous rocks lying beneath the limestones. That the ores are the result of uprising siliceous waters is established by the facts already set forth. That these waters were hot is extremely probable, since there is abundant geological evidence that the successive igneous intrusions heated the entire district and that fumarolic activity prevailed, as is shown by the occurrence of axinite, tourmalines, and other minerals in the rocks.

As already stated, the ore deposit has been formed since the gabbro intrusion and the accompanying metamorphism of the sediments. The gabbro is rich in augite, mica, and iron ore, and often contains pyrite in considerable abundance. Some of this pyrite seems unquestionably to be of primary origin. The occurrence of metallic sulphides in such basic rocks is, however, well established by observations elsewhere, notably those of Vogt in Sweden, Adams in Canada, and Kemp in the United States. No definite evidence has been obtained proving that the Elkhorn rocks are especially rich in silver and lead, yet the presence of metallic sulphides and the geological facts all point to the gabbro as the source of the metallic contents. Ore deposition probably took place after the intrusion of the granite batholith. The profound changes resulting from the presence of this enormous mass of rock, which obliterated the former rocks over an immense area and produced a great heating about the borders of the intrusion, all indicate conditions favoring a shattering of the gabbro and a leaching of deep-seated portions of the mass by uprising waters following the granite intrusion. It is evident also that the pneumatolitic action accompanying the cooling down of so large a mass must have greatly stimulated the circulation of hot waters and vapors; although no definite evidence of former hot-spring action is now recognizable by any surface deposits, the observed facts all point to the former presence of hot waters. It is true that there is a certain amount of evidence proving a differentiation of the granite about its borders, and that these basic differentiation products may have been leached by the circulating hot water, but it seems reasonable to suppose that the gabbro, a more basic rock, afforded some favorable physical conditions for the leaching and extraction of its precious-metal content. The gabbro now exposed in the district is very fresh, or shows only surface alteration, and therefore it could not have been leached, as such action would leave definite signs of solfataric action. The leaching must have been in more deeply buried portions, and the uprising mineralized waters, following lines of least resistance, were concentrated by the impervious shales in the course now marked by ore shoots. The pinching out of the deposit in depth and its impoverishment in values in the deeper workings are at first sight more favorable to the theory of precipitation from descending solutions than of precipitation out of ascending waters. As already shown, however, the deposition took place on the under side of a pitching anticlinal fold, and this is positive evidence that the waters were ascending currents. Moreover, the workings show that the ore channels do not disappear in depth, as quartz is seen in the 2,300-foot level, the bottom level of the mine, where it still carries metallic sulphides. Besides, the verticals of the Black Hills region—of whose existence and character we now have very definite data—are examples of extremely small and often barren fissures, sometimes mere cracks in the rock, which serve as feeding channels for the siliceous ores formed by replacement along the bedding planes between limestones and less soluble shales or quartzites.

It should be remembered, also, that in solutions slightly varying conditions may change or even reverse the chemical action, solution and deposition being really relative terms. Varying temperature and pressure are the factors which disturb chemical equilibrium. A solution may dissolve metallic sulphide under the pressure and temperature prevailing during the cooling down of the granite batholith and carry them upward without precipitation. In such cases physical conditions did not favor precipitation, and the sulphides were deposited only when relief of pressure and cooling have permitted their precipitation. One can conceive that under stable conditions uprising hot waters flowing in trunk channels would show a lower zone in which the waters would be capable of taking the metals into solution; above this another zone where the waters would hold metallic sulphides in solution but would not precipitate them; and a third zone, above the last, in which precipitation would occur. Near the surface the least soluble metallic sulphides would have all been precipitated and the hot waters issuing as springs would deposit only silica and the more readily soluble salts. It must, of course, be understood that in this theoretical arrangement there would be a gradation from one zone into another, and that the metals should show a fairly orderly vertical distribution. This is in fact what we find in the Elkhorn deposit, where the ores show galena underlain by zinc and passing into pyritiferous ores in depth. The occurrence of this deposit on the border of the granite batholith is analogous to that of many of the great ore deposits of Montana. The Granite Mountain mine, the Drumlummon, the mines at Winston, and the Whitlatch Union lode, near Helena, are all familiar examples of rich ore deposits formed in veins traversing similar contact rocks.

SECONDARY SULPHIDE ENRICHMENT.

The extensive oxidation of ore bodies, converting them in the upper part of the mine into carbonates and oxides, has been accomplished by a partial leaching out of the silver contents from large masses of ore. This oxidizing action with lixiviation is less prominent in depth, and, in the lower ore bodies, has gone no further than to form a cap of oxide ore above the ore body. There is, however, abundant evidence that oxidizing waters have penetrated to the greatest depth yet reached in the mine, 2,300 feet on the dip. The ores from this level show partially altered galena with oxide coatings, and tetrahedrite partly converted into sooty black sulphides; moreover, open water courses are found in the dolomite, and the quartzose ore, taken from the freshly opened face of the 2,300 quartz body, showed the sulphide minerals partially oxidized, while the quartz was porous and held little rust-stained cavities.

It has been shown[1] that where ore bodies are leached by oxidizing waters the descending solutions may precipitate their metallic contents by reaction with lean primary sulphide ores. This reaction is prominent, however, only where the original sulphides contain much pyrite or other iron sulphides. The absence of such ores in the shoots worked in the Elkhorn mine would explain the absence from the ore bodies thus far worked, but it does not explain why they do not occur in the pyritic ores found in the lower levels. There is, it is true, some evidence indicating the secondary nature of tetrahedrite and of local bunches of secondary sulphides, but it appears probable that the failure to form large bodies of such secondary ore is due to the massive and unbroken condition of the ore bodies which were not freely penetrated by descending waters. Moreover, the mine waters are not acid and do not contain ferric sulphate, so that it is evident that favorable conditions for secondary enrichment did not generally exist. The impoverishment of the ores in depth may perhaps be due to a slight enrichment of the upper levels. While it is not believed that galena exercises any amount of action upon descending solutions, it must be admitted that some of the very high-grade galena found in the mine, that was partly altered and showed sooty films along the cleavage plates, may have been rich in silver sulphides. However, the impoverishment of lead-silver deposits in depth, and their passage into low-grade zincky ores, is a common phenomenon in the mines of the Rocky Mountain region. It has been especially noted by Rickard.

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[1] Enrichment of mineral veins by late metallic sulphides, by W. H. Weed: Bull. Geol., Soc. Am., Vol. XI, 1900, pp. 179-276. Enrichment of gold and silver veins, by W. H. Weed: Trans. Am. Inst. Min. Eng., Vol. XXX, 1900, pp. 424-448.

AGE OF THE ORE DEPOSIT.

The geological evidence which has been presented in the foregoing pages proves that the rock metamorphism of the strata containing the ore deposit is mainly the result of the intrusion of the granite batholith, and it follows from this that the ore deposit is younger and has not suffered metamorphism. It is believed that the deposit was formed shortly after and is a sequel to the granitic intrusion, and hence is of late Eocene or early Miocene age. The rhyolite intrusions and outbursts which took place at neighboring localities in middle and late Miocene time were, it is true, followed by ore deposition at some places, but there is reason to believe that the Elkhorn deposits were not the result of this period of dynamic activity, but that, like those of Butte, they preceded the rhyolitic intrusions.

CHAPTER IX.

NOTES ON OTHER MINES OF THE DISTRICT.

Although the Elkhorn mine is the only one in the district which has yielded any large amount of mineral wealth, there are a number of other fractures which are interesting scientifically and which have been more or less developed in the last twenty years. None of them have as yet been developed into paying mines. This is in large measure due to the fact that the ore which has thus far been produced has been of extremely low-grade character. So far as known, none of these mines show the favorable physical conditions which prevail in the Elkhorn. The following brief notes have been made on the deposits:

The C. and D. mine is situated about a mile north of the Elkhorn. The ore body lies in the marbleized Madison limestones, near the granite (quartz-monzonite) contact. The mine has a shaft 250 feet deep, with several levels, and a tunnel which crosscuts through the limestone to the granite contact. The mine was not examined in detail, as it was not accessible. The deposit is not a true fissure vein, but according to Mr. Kelley contains deposits of low-grade pyritic ore, with occasional bunches of galena in limestone, the former ore being too low grade to pay expenses under ordinary circumstances. The mine has been leased at various times to different parties, and in 1898, by reason of an extremely favorable contract with the East Helena smelter, which desired its oxidized iron ores, it was worked for a while. A considerable number of car loads of ore were shipped, although the ore ran only from $1.50 to $2 per ton in gold and was low in silver. Several car loads of galena have been shipped from the mine, coming from chambers in the limestone. The granite contact shows a pyrite lead, but this ore also was too low grade to work. The product of this mine has already been given in the first chapter of this report.

The Keene mine, which lies about 1,000 feet north of the Elkhorn, was worked in a desultory way for about twenty years. It is said to be developed by a 150-foot shaft and by a tunnel running several hundred feet into the hillside and having drifts on the vein. The ore is an oxidized ferruginous material, said to carry good values in gold. It occurs along the bedding plane between an underlying limestone (the Keene limestone) and an overlying argillaceous bed. While the observations made were not detailed enough to show the actual structural relations, it is believed that this deposit is formed along an impervious stratum and that the horizon may be expected to yield workable ore bodies where the contact forms a pitching anticlinal fold, permitting saddle deposits. The mine stopes show some evidence of slipping or accommodation along the contact plane, but as the shaft had caved in at the time the mine was visited and the workings were not safe no detailed study was made.

The Union mine is situated at the head of Alpreston Gulch, in the limestones near the granite contact. The property has yielded several railroad car loads of silver-lead ore, but the ore bodies are not continuous and the average value of the ore is said to be too low to warrant working. The property was worked in the early eighties, and the development in 1884 consisted of an 80-foot shaft and a 240-foot tunnel. The ore extracted at that time is reported to have carried 80 to 350 ounces of silver per ton.[1]

The Dolcoath mine differs from those previously mentioned, and indeed, so far as known, from all other property known in the State. The ore shows free gold in the upper weathered parts of the body, and the unaltered portion consists of glittering metallic spots of bismuth sulphide and telluride (bismuthinite and tetradymite). The ore-bearing stratum is from 15 to 18 inches thick and dips northeast at an angle of 45° to 50°, the strike being N. 5° W. The mine has been opened by an incline shaft 170 feet deep, with a level at 100 feet, and another at the bottom of the shaft driven in both directions. The ore-bearing stratum is clearly an impure limestone altered by contact metamorphism and now consisting of garnet (grossularite) with lesser amounts of diopside and spots of calcite. The rock is coarsely granular, the garnet being the coarser mineral, and the diopside filling interspaces; the calcite exists in strings, veinlets, and bunches, which are evidently the filling of drusy cavities also showing garnet crystals and of fractures in the garnet itself. The calcite masses are, however, often similarly oriented and appear to be singular individuals which seems opposed to their deposition in open spaces. The ore minerals have been examined in the chemical laboratory of the Survey by Dr. H. N. Stokes, who reports that they consist of bismuth sulphide (Bi_2S_3) 86.7 per cent, bismuth telluride (Bi_2Te_3) 13.3 per cent. Dr. Stokes says that much of the sulphide was found to be free from the telluride. Whether the latter is tetradymite with or without sulphide could not be positively determined, nor could it be determined which mineral carries the gold. Bismuth sulphide is the mineral bismuthinite, and it has altered in the upper portion of the ore deposit to the carbonate bismutosphærite, which occurs as a yellow, powdery material, and has dark-brown dendritic markings. The tetradymite contains some copper, and in this respect accords with the analysis made by Genth, which is recorded in Dana's Mineralogy. In the altered material this copper has stained the rock with malachite. The bismuth minerals occur scattered through the ore in minute grains disseminated throughout the garnet, in larger grains in the diopside, and as particles varying up to a quarter of an inch across, which appear frequently to be associated with the calcite.

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[1] Report of Director of Mint on Production of Gold and Silver, Washington, 1885, p. 304.

A study of the partially altered ore leaves no doubt that the gold occurs as a constituent of the bismuth minerals and that it has been freed and left as native gold by their oxidation. The gold is somewhat dull and rusty and has the habit often observed by the writer when it is undoubtedly derived by oxidation from tellurides. The ore stratum is overlain by impure marble and underlain by a similar lime-silicate rock. A short crosscut driven into the foot wall showed the presence of an intrusive sheet of gabbro-diorite at a distance of about 18 feet from the ore body. The ore in this stratum is probably the result of pneumatolitic action, due either to circulating vapors or, more probably, to circulating hot waters rising upward through it. As suggested by Dr. Barrell, the metamorphism of an impure limestone would produce a somewhat porous rock, since the minerals produced by contact metamorphism occupy less volume than the original rock. The action is somewhat analogous to that of the baking of brick, in each case the action being due to heat. An examination of thin sections of the wall rock has been made by Dr. Barrell and shows that they are purer limestones and that the resultant product is far less pervious to water than the ore-bearing stratum. It is believed, therefore, that as the rocks are tilted and slightly folded the pressure was not sufficient to close up the pores in the rock, and that, being confined by the relatively impervious stratum above and below, the uprising waters followed this horizon and deposited their metal contents, together with calcite, in the interstices of the rock.

It has been impossible to obtain any data concerning the various other properties of this district, as all the shafts are filled with water or the tunnels are inaccessible. The report of the Director of the Mint upon the production of precious metals for 1884 contains a short account of a number of mines upon which considerable development work had at that time been done. Thirteen properties are mentioned besides the Elkhorn mine. Three of these—the Union, C. and D., and Keene mines—have already been mentioned; the others include a number of ore bodies situated close to the Elkhorn mine, none of which have, so far as it has been possible to ascertain, been worked within the last ten years. The notes mentioned give a little information concerning the geological character of the ore deposit.

The Relief mine, located a quarter of a mile northeast of the Elkhorn, is said to have shown at a depth of 20 feet a 12-foot vein of silver ore giving assays of 50 to 100 ounces per ton.

The Paymaster, located 400 yards north of the Elkhorn mill, showed a 4-foot face of ore along a slate-dolomite contact.

The Homestake and the Dunstone.—The Homestake, three-fourths of a mile northwest of the Elkhorn, and the Dunstone, 600 yards northwest of the Elkhorn, show ore bodies in dolomite.

The Monte Cristo, the Luxenburg, and the Mountain View.—The Monte Cristo, 1,000 yards west of the Elkhorn, contains a 10-foot vein of copper ore lying in slate and granite. The Luxenburg, one-half mile south of the Elkhorn mine, showed at a depth of 35 feet a 6-foot vein of ore carrying copper and lead, as well as the precious metals, the country rock being granite. To the north of the Elkhorn mill, the Mountain View property, situated 1½ miles up the gulch, is said to have shown a 3½-foot vein of silver-lead ore in slate and syenite.[1]

IRON MINES OF ELKHORN PEAK.

On the north shoulder of Elkhorn Peak, about 700 feet below the summit, there are two deposits of iron ore that are exposed by open cuts and underground drifts, and from which considerable ore has been shipped at various times in the last ten years. The property is reached by a steep but fairly good wagon road, leading from Elkhorn up Alpreston Gulch and over a spur of Elkhorn Peak, a distance of about 4 miles. The ore bodies occur beneath the great marble inclusions in the andesites of Elkhorn Peak, and form the white cliffs so prominent in all views of this mountain. These inclusions are underlain in places by thin seams or lenses of magnetite and garnet. In general these seams are too thin to be of economic value, but on the northwest side of the peak they are thick enough to constitute workable ore deposits. The ore is always found along the bottom of the marble mass, and is undoubtedly a replacement of it. It rests on andesite, which is badly decomposed and rich in iron wherever it was seen exposed. The marble above the ore is not over 15 feet thick. The ore itself is a massive fine-grained magnetite, showing rare grains of chalcopyrite and an admixture of garnet. Green stains of copper carbonate occur on the weathered crust. The mass of garnet present varies considerably, and it is possible to obtain very high-grade ore by sorting the material. This ore is said to carry small values in gold, but no assays were made to prove the accuracy of this report. The only use for iron ores in Montana as yet has been in the smelting establishments, as a flux for siliceous ores. The Elkhorn material has all gone to the East Helena smelter. The property is reported to have been bonded in July, 1900, to the Helena and Livingstone Smelting and Reduction Company for $15,000, as a source of flux for the smelter just mentioned. Deposits similar to those at Elkhorn have been noted by the writer about igneous intrusions in other parts of the State, notably in the Little Belt Mountains. They are commonly regarded as the result of the alteration of contact deposits of pyrite. Cross and Emmons have noted similar deposits at numerous places in Colorado, and have ascribed them to the decomposition of pyrite. It has been suggested that the Elkhorn deposits might be altered limonite replacements formed by waters flowing down the andesite surface underneath the marble. Of this, however, there is no proof, whereas there is definite evidence to show that similar deposits elsewhere have originated from the alteration of pyrite masses.

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[1] Report of the Director of the Mint for 1884, pp. 304–305.

The Jacquemin mines are situated in the gulch of Iron Creek a mile northwest of the town of Elkhorn. They were worked energetically during the summer and fall of 1898, but in 1899 they were closed down, and the bad air of the tunnel made an examination of the ore body impossible. The mines were worked for a while to supply a temporary demand for iron ores for the East Helena smelter. The opening up of the War Eagle mine, near Helena, furnished a nearer and cheaper source of supply, and this property was closed down. The workings comprise a tunnel driven for several hundred feet through granite to a contact of altered Cambrian (Starmount limestone). The ore is oxidized and appears to be a mixture of hematite and limonite, and is probably an alteration of a contact deposit of pyrite.

The Elkhorn Queen is situated east of Queen Ridge and just outside the limits of the map. This property, which was shut down at the time of the writer's visit, has been visited by Mr. Kelley, who states that it shows a pipe of porphyry in limestone, with a shell of ore about the contact. During May and June, 1900, more than 1,000 tons of ore have been shipped from the Elkhorn Queen to the Peck concentrator at East Helena. The vein is said to be 24 feet wide, and while values are low the immense quantity makes it easy to mine, and although small profit per ton can be realized the large tonnage is expected to make it pay large dividends.

FUTURE OF THE DISTRICT.

The closing down of the Elkhorn mine and the dismantling of the surface works is by many regarded as the end of the mining industry of the district. From the daily press comes recent information that the Elkhorn Company's property has been sold and will be reopened. If this be true it is to be hoped that some prospecting will be done to see if the main slate-dolomite bedding plane (or contact) does not form another saddle to the north. If the extension of the 300-foot level showed such a bend, as a result of another pitching arch of the strata, another ore body can be confidently looked for. Moreover, the only hanging-wall crosscuts have been driven in the intervals between the arches carrying the ore. The 1,050 hanging-wall crosscut passed through, at 60 feet from the level, a blue limestone whose contact was marked by ore. If ore was found here—in an unfavorable locality—there is reason to believe that ore bodies will be found in the saddle above the big ore shoots. In the well-known "saddle reefs" of Australia, which are deposits formed in pitching anticlines, ore bodies are found in successive saddles one above another. The vertical sections commonly given in text-books and the illustrations in descriptive reports do not disclose the close analogy to Elkhorn which the descriptive text shows to exist. It is certain that at Elkhorn there were at least three impervious strata—the Elkhorn shale, the contact cut at 60 feet above it, and the shale belt of the Keene mine. These three contacts are all marked by a little ore, and the contacts should be carefully searched where pitching arches would afford favorable conditions for ore shoots.

MICROSCOPICAL PETROGRAPHY OF THE ELKHORN MINING DISTRICT, JEFFERSON COUNTY, MONTANA.

By JOSEPH BARRELL.

INTRODUCTION.

In this report there will be presented an account of the petrographical features of the various rock types of the Elkhorn mining district. The work is the result of a careful study of the rocks and their sections in the laboratory of the Sheffield Scientific School of Yale College, under the supervision of Prof. L. V. Pirsson, this paper on the petrography forming a chapter in a thesis entitled The Geology of the Elkhorn Mining District, presented for the degree of doctor of philosophy in May, 1900. This report treats first of the unaltered igneous rocks, and separately of the altered sedimentary rocks, the metamorphism of which was produced by the heat and vapors of the igneous intrusions.

UNALTERED IGNEOUS ROCKS.

Under this heading an account will be given of the igneous rocks of the district that are unaltered by contact or later weathering. As they form part of the series of rocks formed from the earlier Tertiary igneous activity of this part of Montana, the results of the study apply to a widespread area as well as to the Elkhorn district. A general account of these has been given by Mr. Weed in the paper preceding this, and it is to be noted that, while no unusual types are found, considering the limited area a great many varieties are represented, belonging to consecutive epochs of eruptive activity. Referred with probability to the oldest period are a number of dikes emanating from a syenitic magma but showing extreme differentiation from acid to basic types. These have been observed in the Elkhorn mine and also in the southern part of the district within a mass of Starmount lime-silicate rocks isolated from the other sedimentaries by later eruptives. Following these at an unknown interval came a period of great eruptions from dioritic and gabbroic magmas, forming the Black Butte stock of gabbro, the laccolithic intrusion of diorite-porphyry, numerous dioritic and gabbroic dikes, the intrusive and extrusive areas of andesite found in the northern and southern parts of the district, and perhaps the Cemetery Ridge stock, though the relations of the latter to the other eruptives are not well shown. After this there was an irregular and branching intrusion of quartz-diorite-porphyry across the southern part of the district, and finally came the breaking of the quartz-monzonite of the batholith across the western border. The intrusion of aplite dikes through the quartz-monzonite and the adjacent sedimentaries marks the close within this area of the eruptive actions.

The plan of this report is to describe the microscopical features of these rocks, pointing out any peculiarities, to give the chemical and mineralogical compositions, and to indicate, where possible, what relations may exist among them. Chemical analyses[1] of the principal rock types are given, but in the descriptions these are supplemented throughout by estimated mineral or chemical compositions as determined by the microscope.

In those classes of rocks where the minerals are clearly separated from one another an estimate of the chemical composition sufficiently accurate for many purposes may be obtained by the use of the microscope. The percentages of the several minerals and their composition are first determined. In those minerals, such as the pyroxenes or hornblendes, where certain elements may replace each other in unknown quantities, the general character of the rock will enable one to decide approximately what composition to assign to them, but as they usually form but a small part of the rock the final error resulting from this source is correspondingly reduced.

The composition of the feldspars is usually susceptible of accurate determination. Where possible the method of Michel Lévy[2] is used, depending upon the extinction angles observed in crystals twinned according to both the albite and Carlsbad laws and cut nearly perpendicular to the clinopinacoid. Where the section is not favorable for the application of this method a variety of other methods may be employed, such as the relation of the vibration direction to the cleavages shown in clinopinacoidal sections and the positions of the optic axes.

For estimating the percentage of the constituent minerals of the section any one of a number of methods may be used, that which is chosen depending upon the degree of precision desired. In this work the method employed is as follows:

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[1] These analyses were made for me by Dr. H. N. Stokes in the laboratory of the United States Geological Survey. The careful nature of the work of Dr. Stokes is well known, and it is a pleasure for me to call attention to the close correspondence between the mineralogical and chemical compositions of the rock types described herein.—W. H. WEED.

[2] Étude sur la détermination des feldspaths, 1894. Same, second fascicle, 1896. On the determination of plagioclase feldspars in rock sections, by George F. Becker: Am. Jour. Sci., 4th series, Vol. V, May, 1898, p. 349.

The field of view of the microscope is divided into quadrants by the cross hairs, and these are mentally divided into sectors which are thirds, fifths, or smaller fractions. By taking such a power of objective that the component to be estimated is represented in the field of view by a fair number of crystals, the latter can be mentally collected together and packed into one quadrant, and the fraction which it fills estimated.

If not enough of the section can be seen in one field of view to give a representative idea of it, a number of gages must be taken, this being done while the minerals are under study, so that no time is consumed, and it will be found that with a little practice a fair degree of precision may be reached. As the one thin section under study is not presumed to be an accurate average of the rock mass, it is not often that a more exact method of estimation will be called for.

In the case of holocrystalline rocks, where the writer has been enabled to check this method of estimating the mineral and chemical composition by comparison with laboratory analyses, it is found that the error in any one element should be less than 1 per cent and is often less than one-half per cent.

BLACK BUTTE STOCK AND ASSOCIATED DIKES.

This stock, more fully described elsewhere, is an intrusion half a mile in diameter, with very irregular boundaries, situated three-fourths of a mile northwest of the town of Elkhorn. It has broken through the Lower Paleozoic limestones, and on the west is itself sheared off by the later intrusion of the batholith. On the other three sides are many small outlying stocks and stock-like dikes, consisting of rocks of similar composition and connected with it in origin. The cliffs and loose bowlders present a coarse-grained, weathered surface of a dull-grayish black. On fresh fractures labradorite shows as a deep-gray groundwork, biotite in intense black clusters, and augite and hornblende as dull black crystals, usually with poorly defined boundaries. In the coarser-grained varieties these distinctions can be readily made out, but in the denser forms only a fine-grained, uniformly dark surface is presented to the eye.

The coarseness of texture shows no very marked relation to the nearness to the walls. These appear to have been thoroughly heated before crystallization took place, and other causes have been chiefly operative in determining the granularity and general appearance of the rock.

The material of this intrusion is typically a gabbro, but shows considerable variation in composition, leaning in some places toward the anorthosites, in others toward the pyroxenites, and passing in the outlying dikes into diorites. In the following table the composition of the representative rock is given, and is compared with that of the gabbros of the southwestern Adirondack region, to which this rock bears a strong resemblance.

Analyses of gabbros from Montana and New York.

Constituent.	A.	B.
SiO_2	47.44	46.85
Al_2O_3	18.21	18.00
Fe_2O_3	5.37	6.16
FeO	6.05	8.76
MgO	5.53	8.43
CaO	9.98	10.17
Na_2O	2.58	2.19
K_2O	1.17	.09
H_2O at 110° C	.13	.30
H_2O above 110° C	1.08	
TiO_2	1.38	....
CO_2	None.	....
P_2O_5	.68	....
S	[a] .03	....
Cr_2O_3	None.	....
NiO	None.	....
MnO	.06	....
BaO	.08	....
SrO	.08	....
Li_2O	Trace.	....
	99.85	100.95

[a] Undetermined whether sulphide or sulphate.

A. Normal gabbro from west side of Black Butte, not far from the limestone contact, Elkhorn, Mont. Analysis by H. N. Stokes.

B. Hypersthene-gabbro from the southwestern Adirondacks, New York. C. H. Smyth, jr., American Journal of Science, July, 1894.

The rock is seen to be a normal gabbro, but differs somewhat from any from Montana yet described by the United States Geological Survey in having a rather high percentage of alumina compared to the amount of silica. This expresses itself in the mineral composition by an abundance of labradorite.

To show the variations in composition within the stock and also in the adjacent dikes the following table is given. The percentages are estimated by the microscope and are given by volume. The magnetite being the mineral of greatest specific gravity, the most noticeable change in converting these into percentages by weight would be a slight raising of the amount of magnetite and a lowering of the labradorite. For purposes of comparison the composition by volume, being that directly obtained by the microscope, will suffice equally well.

Mineral composition of igneous rocks from Black Butte stock and associated dikes.

Mineral.	1.	2.	3.	4.	5.
Labradorite	37	63	67	70	33
Augite	45	20	8	1	8
Hornblende	8	2	15	19	....
Biotite	6	10	6	8	1
Magnetite	4	4	1	.5	4
Quartz	....	1	3	2	....
Apatite	.5	....	....	....	....
Zircon	.1	.1	....	....	....
Hypersthene	....	....	....	....	4
Groundmass	....	....	....	....	50

1. Gabbro from near northern side of main stock (144).
2. Gabbro, west side of Black Butte, near limestone contact. See analysis on page 514, by N. H. Stokes (155–156).
3. Gabbro-diorite from small intrusion half mile north of Black Butte (64).
4. Diorite. Inclusion in later eruptive 4,000 feet south of Black Butte (17).
5. Andesite-porphyry, from same inclusion as No. 4; a different portion of same mass (90).

NOTE.—The numbers in parentheses after all tables refer to field numbers given to localities and to specimens taken from them.

The similarity of Nos. 2, 3, and 4 is to be noted, No. 2 coming from the stock, while 3 and 4 are from outlying intrusions 6,000 feet apart. The latter two closely resemble each other in microscopic appearance as well as in composition, and all are blackish-gray holocrystalline rocks, noted under the microscope for their large percentage of labradorite, which runs in composition from $Ab_1 An_2$ to $Ab_3 An_4$, the entire series possessing also a notable amount of biotite.

No. 2 compared to No. 1 shows the variation in composition within the same stock, and Nos. 4 and 5 exhibit a similar contrast for an outlying fragment of the same magma, originally an intrusion, but now held as an inclusion within the quartz-diorite-porphyry, which occupies a considerable area south of Black Butte.

In regard to the original relations of Nos. 4 and 5 to the strata which once surrounded them, not much can be said, since they are now parts of an inclusion within a later eruptive. Their difference in mineral composition between themselves must be noted, however, as indicating the rapid changes which may take place within the same intrusion. The association of minerals is seen on comparing the several sections. Free quartz exists in those with much biotite and hornblende, even in the presence of those minerals characteristic of the more basic rocks, but avoids those parts of the stock in which the magnetite and augite are high and the biotite and hornblende low. It is to be noted that where the quartz is present the labradorite feldspars are zonally built in the outer parts, indicating a greater content of soda and silica and a transition toward the albite molecule, a feature quite absent in the most basic gabbros.

The greater percentage of labradorite in certain sections of the stock, and its matted manner of occurrence, when taken in connection with the fact that in the gabbros it is the first mineral to crystallize, suggest the explanation that the cause of the segregation has been the cooling of the walls. The moving and settling of the magma within the stock while undergoing crystallization would afford opportunity for the labradorite to crystallize against the contacts, exhibiting a parallelism in orientation, while the other constituents were still in the fluid condition, resulting in a concentration of the labradorite at the sides and of the iron ores and augite toward the center. If this is the true interpretation it is worthy of note, since in the more acid magmas it is the iron ores and ferromagnesian minerals which are the first to crystallize and which by that means are often concentrated near the borders of an intrusion.

The thatched or matted manner in which the labradorite crystals lie upon one another is not strictly confined to the margin, and the same process may have been continuous for some distance inward, provided there was a slow movement of material within the throat as the crystallization proceeded.

ROCKS OF THE CEMETERY RIDGE STOCK.

This area of eruptive rock, a half mile in width by three-fourths of a mile in length, lies immediately east of the town of Elkhorn. Like the one previously studied, it has broken through the Paleozoic limestones and possesses a very irregular margin. At the surface it is entirely isolated from contact with all of the other eruptives of the district, and this, in addition to its highly altered condition and the absence of fresh material for study, renders its relationships somewhat doubtful. The rock where freshest is seen to possess a holocrystalline texture and the appearance of a diorite. In its present condition it shows the influence of both extensive subaerial and subterranean alteration. The surface weathering has produced rust-colored bowlders and a general decay for considerable depth, but the more extensive form of alteration has resulted in the production of serpentine and probably other hydrous ferromagnesian silicates also, leaving in places no trace of the original holocrystalline texture. These alteration products are well exposed in the railroad cut immediately south of the Elkhorn station, showing as white to yellow, many-jointed surfaces. Occasional nuclei of the original igneous rock point conclusively to the origin of the hydrous ferromagnesian silicates, and that the alteration process is not a surface one is shown by the occurrence of the same materials in the Elkhorn mine at depths of 800 feet below the surface on a drift driven southward to prospect this locality. As to the character of the unaltered rock, only the following notes are available, the mineral compositions being given by volume and estimated by the use of the microscope.

Mineral composition of rocks of Cemetery Ridge stock.

Mineral.	A.	B.	C.	D.
Orthoclase	2	80	33	
Microcline	1			
Labradorite ($Ab_3 An_4$)	43			
Labradorite (Ab An)			44	
Total feldspar	46	80		75
Quartz			15	5
Biotite	1	8		
Hornblende			5	15
Pyroxene	50	0.8		
Pyrite	3	2	2	2
Titanite		2	1	
Garnet		6		
Decomposition products		1		3
	100	99.8	100	100

A. Specimen from half a mile west of the town of Elkhorn, near the northeastern margin of the stock (12).

B. Specimen from a dike cutting the limestone on the south drift of the 1,050-foot level of the Elkhorn mine, at a point under the northwestern margin of the stock (187).

C. Quartz-monzonite from the Elkhorn mine. Collected in 1896 by Mr. W. S. Kelley.

D. Specimen from a dike conformable to the limestones exposed on the railroad 2,000 feet west of the stock (8).

The rock from the margin of the stock, represented by A, is dense and dark in appearance, and is seen to be a gabbro. The fragments of metamorphosed limestone found within the stock at the surface, and still maintaining their proper orientation, indicate that the present surface is near the former roof. In this locality, then, basic segregations would be expected to occur, and deeper down the stock may be more siliceous.

The dike found in the mine, and whose composition is given under B, is so near to the main stock that the probability of its relationship to the latter is strong, though by no means proved. The rock is fresh and granular in appearance, of a light-gray color, and with many sparkling points of pyrite. It is essentially an orthoclase rock, and shows affinities with the syenite dikes found in the extreme southern part of the district. Its unlikeness to A is another indication that, though in proximity to the Cemetery Ridge stock, it may not be related to it. Its further discussion is reserved for the section on syenites.

The rock given under C has the composition of an acid diorite or quartz-monzonite, differing conspicuously from B in possessing much plagioclase and quartz. It was collected from the same drift as B, but owing to its unlikeness can not be regarded as belonging to the same intrusion as the latter.

The rock whose mineral composition is given under D is a microdiorite occurring in a dike 50 feet in thickness, comformably bedded with the limestones, but exposed for only a short distance. It is quoted because it is the large intrusive nearest to the stock, but does not have any evident relation to it.

In default of further material from the stock itself, its general character and affinities remain in doubt, the probability being that it is a diorite, passing in places into a gabbro, perhaps in other places into a quartz-monzonite.

SYENITE DIKES.

There are a number of thin dikes and sheets varying greatly among themselves but possessing the common characteristic of being without quartz and containing an abundance of alkaline feldspar. Owing to their thinness, and also to the fact that they are usually bedded with the strata, they are very liable to escape observation except where exposed by fresh cuttings. The only exposures noted have been in the Elkhorn mine workings and in a railroad cut in the southern part of the district. For these reasons they may be more abundant within the district than is supposed, especially as, where occurring near other eruptives, they are sometimes not readily discriminated in the field.

Those found in the extreme southern part of the district are in a mass of metamorphosed Starmount argillaceous limestones, 400 feet in thickness, entirely isolated from the neighboring sedimentaries, being underlain by intrusions of quartz-diorite-porphyry and andesite and capped by the diorite-porphyry laccolith. Within these light-colored, calcareous, metamorphic rocks they occur as sheets and dikes from a fraction of an inch to 18 inches in width. They range from white, coarsely granular rocks, consisting almost entirely of microcline and hardly to be distinguished from the inclosing strata, to shonkinites, dark in color and coarsely granular, in which half of the rock consists of augite and biotite.

Before describing them in detail, a synopsis will be given of their mineral composition, by volume, as estimated by the microscope.

Mineral composition of the Elkhorn syenites.

Mineral.	A.	B.	C.	D.
Orthoclase	80			49
Microcline		88	73	
Labradorite			4	
Anorthite				5
Biotite	8			25
Augite	.8	5	20	20
Ægirine				1
Apatite		.2	.1	
Titanite	2	1	3	
Garnet	6	4		
Pyrite	2			
Secondary products	1	2		
	99.8	100.2	100.1	100

A. Garnetiferous syenite from the 1050 south drift of the Elkhorn mine, a dike cutting the foot-wall marbles (187).

B. Bostonite. A dike 5 inches in width, perpendicular to the strata, in the isolated mass of Starmount metamorphosed limestones (170).

C. Augite-syenite. A sheet 18 inches in width in the isolated mass of Starmount metamorphosed limestones. Dikes B and C intersect, but the point of intersection is concealed, and therefore their relations at that point are undeterminable (171).

D. Shonkinite. A sheet of irregular width and occurrence, in the isolated mass of Starmount metamorphosed limestones, 75 feet south of C (174).

The orthoclase or microcline in all of these specimens contains considerable soda, as is indicated by the mottled extinction when rotated between crossed nicols. Carlsbad twinning is common and the microcline shows fine watered effects. The alkaline feldspars were the last minerals to crystallize and hold all the others enmeshed. Where they form the bulk of the rock the individual crystals are from 2 to 3 mm. in length and one-half to 1 mm. in thickness, but in certain places they become much coarser, sometimes giving cleavage faces an inch in length. The crystals show a tabular development along the plane 010, the clinopinacoid. Although in the types rich in alkaline feldspars the latter thus assume something of their crystalline form, the final junction line, with adjacent crystals of the same species, is very irregular, as is to be expected, since these have been the final products of crystallization and have necessarily grown until they have met each other. Thus the rock shows the panidiomorphic structure of Rosenbusch, each crystal of orthoclase assuming somewhat its proper crystallographic form, but exhibiting none of the sugar-granular aplitic structure.

In the augite-syenite and shonkinite a certain amount of plagioclase occurs in scattered and sharply idiomorphic crystals from one-half to 1 mm. in length.

The ferromagnesian components are either mica or augite, or both.

The augite occurs in idiomorphic prisms from one-fifth to 2 mm. in length and shows strong pleochroism, the color along the several axes being bright green, greenish blue, and light yellow. The crystals are scattered throughout the section, though more abundant in some parts than in others. The very striking mottling of C of the above table, the augite-syenite, as seen in the hand specimen, of which a photograph is given (Pl. LXII, *A*), is due to the uneven distribution of the almost microscopic grains of augite.

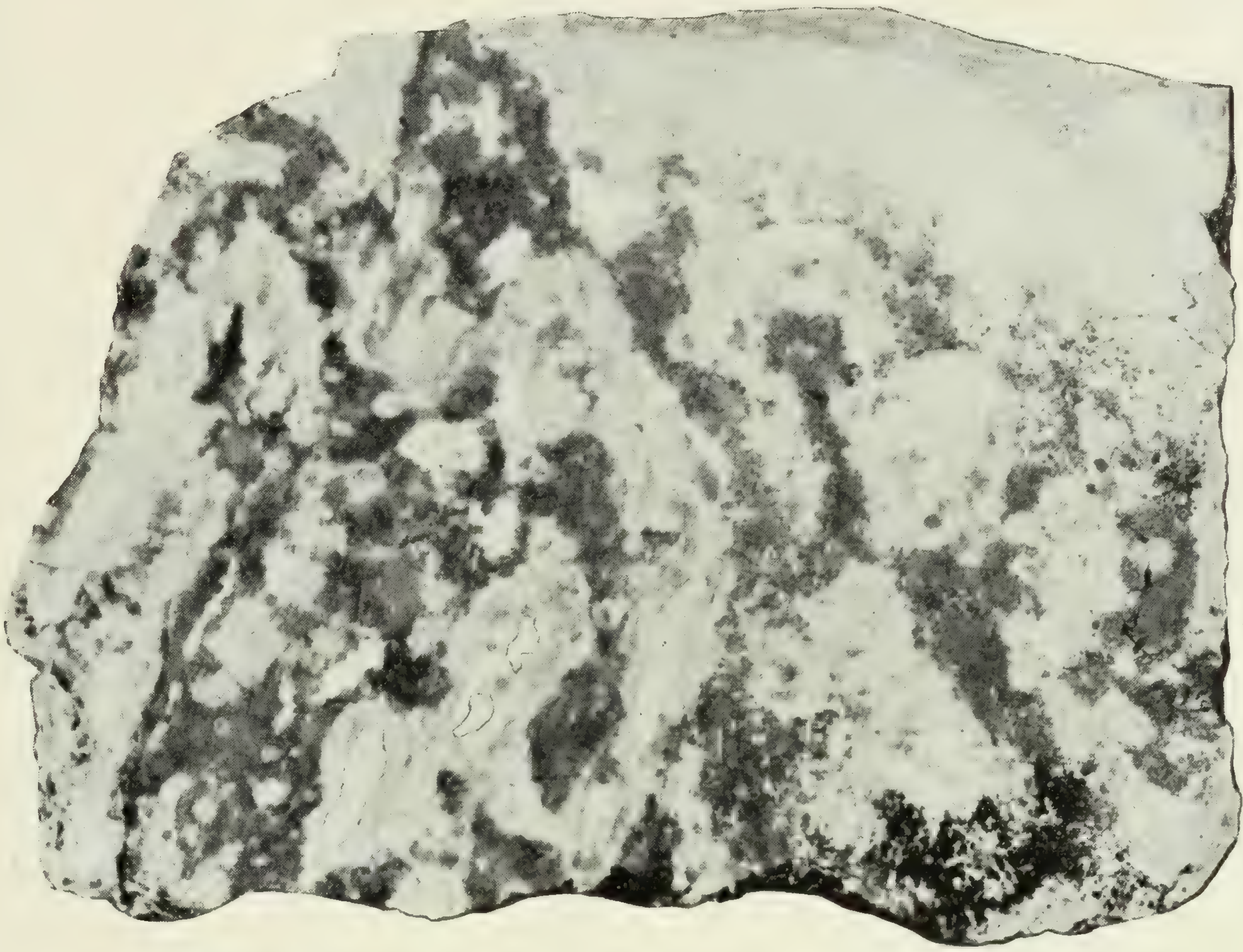
In certain small zones the augites show less pleochroism, presumably from possessing a smaller percentage of iron. In the shonkinite the ægirine exists as an occasional narrow border zone to the augites.

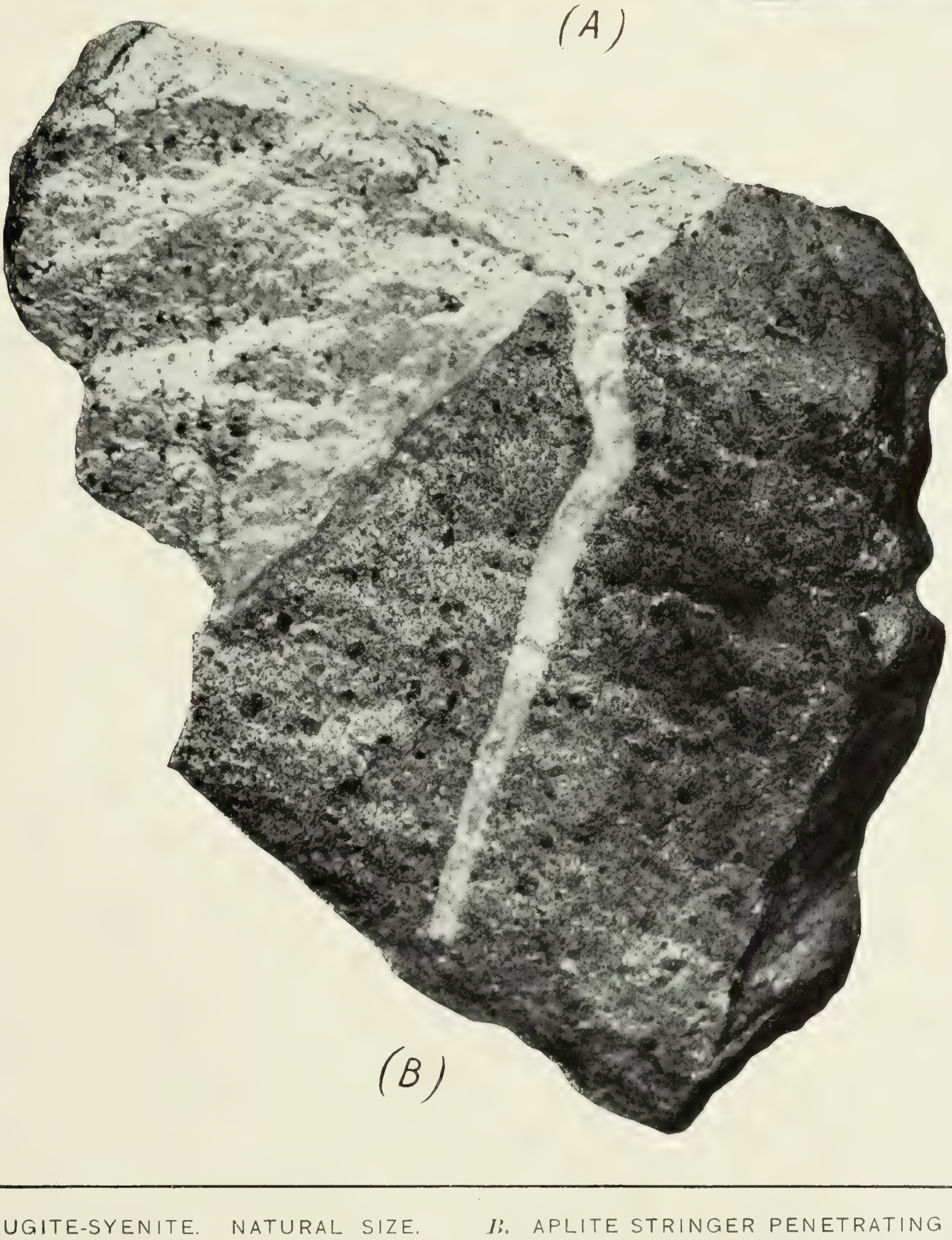
The mica in the syenite from the Elkhorn mine is pale green in color, quite unlike the rich brown of the shonkinite biotite.

The titanite in these rocks is abundant and occurs in the usual lozenge-shaped crystals, averaging 0.3 mm. in length. In A, however, the Elkhorn syenite, it also occurs in anhedral grains, and these are so closely intergrown with a brown garnet that it is only under polarized light that they can be clearly separated.

This close association of the crystals suggests that before crystallization the two may have existed in segregations of somewhat similar molecules, differing from each other in that one kind possessed iron, the other titanium, the two substances on crystallizing being forced to separate owing to their different habits of crystallization.

Titanium is known to occasionally replace iron and silica in andradite, and where it rises to a high percentage and alumina is absent the mineral becomes schorlomite. Titaniferous andradite contains from 1 to 10 per cent of TiO_2, and has been noted in Colorado and at Magnet Cove, Arkansas, as well as at a number of foreign localities. Schorlomite contains from 12 to 22 per cent of TiO_2, and occurs at





A. AUGITE-SYENITE. NATURAL SIZE.

Showing segregation of microscopic augites suspended in microcline and zone of iron-poor augites on the borders of the segregations.

B. APLITE STRINGER PENETRATING ANDESITE. NATURAL SIZE.

Proving later age of the aplite.

Magnet Cove. The relationships of these minerals are seen on comparing the formulas:

Titanite	3 CaO,	3 TiO_2,	3 SiO_2
Andradite garnet	3 CaO,	Fe_2O_3,	3 SiO_2
Titaniferous andradite	3 CaO,	$(FeTiAl)_2O_3$,*	3 $(SiTi)O_2$
Schorlomite	3 CaO,	$(FeTi)_2O_3$,†	3 $(SiTi)O_2$

These relations suggest that in the garnets of the Elkhorn syenites there is probably a considerable admixture of TiO_2. In the specimen from the mine the garnet shows an intergrowth also with the mica.

The garnet occurring in the bostonite is colorless in thin section, and contains fibrous inclusions, which may be wollastonite, as well as a very little calcite. In both places it shows intergrowths with other minerals, and in the bostonite is often poikilitic in the orthoclase. Garnet has been frequently noted in granites and syenites, as well as in gneisses, schists, and hornfels, and therefore no great weight need be attached to its occurrence here; but the absence of its proper crystalline form is exceptional, at least for this district.

On examining the mineral composition of the syenites, as given in the table, the decrease in the alkaline feldspar in C and D is seen to be due to the rise in iron, lime, and magnesia, which, by forming plagioclase and augite, have taken up certain amounts of the alkalies. The marked drop in D is seen to be due to a proportionate formation of biotite, owing to the combination of a considerable amount of potash with iron and magnesia.

These dikes within the isolated mass of metamorphic rocks show no relation to the eruptives which border it on all sides and are evidently more ancient than the latter. They point to some parent reservoir of a syenitic magma which has not been detected and may still lie concealed beneath the surface, or which has possibly been removed by the later intrusions that culminated in the formation of the batholith.

DIFFERENTIATION IN PLACE.

The variable character of these dikes in close juxtaposition, and especially the spotted and mottled surfaces shown in the augite-syenite, and which are reproduced in Pl. LXII, *A*, indicate that extreme differentiation readily takes place. The low percentage of silica indicates a considerable liquidity and the coarseness of texture presumably a leisurely crystallization, two conditions which may be taken as favorable for differentiation. Over certain patches, which may be a foot or more in length, no augite is present, and the rock shows only large and prominent cleavage faces of white feldspar. Surrounding such a white nucleus the microcline is so thickly charged with the augite crystals that the color becomes a blue-black, and the cleavage faces of feldspar on a close examination are seen to be thickly speckled with the included crystals. In the parts where the dark augites are abundant are many smaller spots, half an inch in diameter, free from them, giving a mottled appearance to the whole. The mottling of the augite-syenite does not appear to be due to the intimate admixture of previously differentiated acid and basic forms of the magma, but to a differentiation in place. This is judged from the character of the mottling, and is shown in Pl. LXII, *A*.

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* Dana, System of Mineralogy, 1892, p. 443.

† Op. cit., p. 447.

The contact of the white and blue-black varieties does not show the rounded and drawn-out forms which an admixture of viscous magmas would produce, but, on the contrary, it is an interwoven contact in which the white nuclei pass out in many knotted streamers and form on the surface spots showing a certain parallelism for a width of several inches.

There is a third and intermediate form of the rock, occurring as zones from an eighth to a quarter of an inch in thickness, between the two varieties previously mentioned. In the hand specimen the intermediate zone is seen to be light green in color, and under the microscope the reason is found to lie in the lighter color of the augite crystals, indicating the presence of a less amount of iron.

The segregation has originated, therefore, in place and before the beginning of crystallization. That it originated in place is shown by the form of the two kinds of areas; that it occurred before the beginning of crystallization, and was not produced merely by the settling together of the augite crystals already formed, is shown by the different character of the augites in those two zones where they occur.

The feldspars in growing have shown no power to exclude or even to orient the numerous small crystals of augite and titanite which they include, and thus the same crystal of orthoclase may contain portions of all three zones. It is consequently seen that the crystallization of all the minerals has taken place after the segregation and independently of it. In view of the fact that the augite crystals were considerably heavier than the liquid feldspar within which they formed, it is difficult to understand why a settling out did not take place; but that it did not is shown by the white nuclei being bordered by the dark material on the upper as well as the lower side. For such a differentiation to have taken place within the dike before crystallization, the magma must have presumbably been held for some little time liquid, a condition which implies a general high temperature of the rocks and the near presence at that time of a considerable volume of igneous material, the same condition being indicated by the coarsely crystalline rock structure.

Such a segregation within a narrow dike is in contrast to what has been observed in the Crazy Mountains and which is to be described in a report upon that district by J. E. Wolff and W. H. Weed.[1] There in the same dike occur three varieties derived from the same magma: First, a theralite; second, an acmite-trachyte or the sölvbergite variety of a tinguaite; and, third, a bostonite. The first two exist as inclusions in each one of the others, the bostonite probably acting as a cement to both. The fact that each holds inclusions of the other is taken by the authors as evidence that a mixture of the two, holding fragments already solidified, was intruded as a dike, and hence it is concluded that the differentiation took place before intrusion.

ANDESITES.

The andesitic intrusive sheets, lavas, breccias, and tuffs play a conspicuous part in the geology of the Elkhorn district, which they once covered in large part, if not entirely. They still occupy considerable areas adjacent to it, but within its limits have been largely removed by erosion and are now isolated into three distinct areas. The first occurs on the summit of Elkhorn Mountain, attaining a thickness of a thousand feet or more, and extending north and east beyond the limits of the district. The second is an isolated patch but 500 feet in diameter situated in Queen Gulch, 1½ miles east of the town and on the eastern boundary of the area mapped. The third is an area lying chiefly beyond the map, but of which one end occupies Turnley Gulch, in the extreme southwestern corner. The individual beds, especially of the northern area, show a striking range in mineral composition and manner of origin, grading from quartz-diorites to augite-andesites, and from intrusive sheets to tuffs, whereas the general character of the three areas mentioned is strikingly similar. The andesites present typically a dense, dark, and fine-grained appearance. They are highly elastic to the blow of a hammer, difficult to break, and are cut by numerous cleavage planes which, upon weathering, produce a sharp, angular, and resistant débris. On the highest and most rugged mountain slopes the individual blocks measure several feet in diameter, are heaped together without order, and form rude stairways by which one may readily climb. Here and there rocky promontories, 50 to 100 feet in height, rise from the general talus slope, while in other places the talus is composed of angular material but a few inches in diameter. On flatter declivities and at lower elevations, where the soil has an opportunity to form and the slopes are covered with grass or forest, the surface is smooth and the andesitic nature of the underlying rock is shown only by the finely broken and rust-colored angular material. A close examination of the larger blocks exhibits their original character, whether lavas, breccias, or tuffs, though the natures of the latter are obscured, from having been subsequently metamorphosed and hardened. The lavas are dense, fine-grained rocks, with but little evidence of bedding, sometimes possessing many labradorite phenocrysts, but always with an abundant groundmass. The latter is never coarsely crystalline, and in the first solidification was probably often glassy, though subsequent reheating has in all cases given it a microcrystalline texture.

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[1] Cf. Judd, Composite dikes in Arran: Quart. Jour. Geol. Soc., Vol. XLXI, 1893, p. 536.

All transitions from lavas to breccias are found, though careful examination is often necessary to discriminate the latter, owing to the fact that fragments and groundmass have assumed the same finely crystalline texture in later crystallization.

The tuffs, though departing widely from the common character of tuffs, may be detected by being somewhat softer and lighter than the other andesitic rocks, and by usually showing fine-grained bedding planes, from various admixtures of ash and dust.

In contradistinction to the purely extrusive forms, intrusive sheets of andesite may be found interbedded with them. Sometimes the intrusive nature is demonstrated by the structural geology; at other times it is made probable, where the sheet was thick, by the greater coarseness of crystallization. Often, however, the two modes of occurrence can not be separated, since a thin intrusive sheet may not differ in any particular from the deeper parts of an extrusive flow.

ELKHORN MOUNTAIN INTRUSIVE ANDESITES.

In taking up the petrography of the andesites in detail, the undoubted intrusive forms will first be dealt with. The two great slabs of marble from the Madison formation, contained within the andesites of Elkhorn Mountain, and described in detail elsewhere, are separated by an intrusive sheet of andesite 80 to 100 feet in thickness. In outcropping, this forms a rounded summit 9,000 feet above the sea and 2,000 feet west of the extreme peak of Elkhorn Mountain.

An analysis, by H. N. Stokes, of this intrusive sheet is given and is compared with a couple of closely similar andesites:

Analyses of andesites from Montana and Yellowstone Park.

Constituent.	A.	B.	C.
SiO_2	59.64	60.30	59.48
Al_2O_3	16.64	16.31	16.37
Fe_2O_3	2.33	4.35	3.21
FeO	4.35	1.41	3.17
MgO	2.10	2.39	3.29
CaO	4.59	5.62	4.88
Na_2O	3.31	3.99	3.30
K_2O	4.16	2.36	2.81
H_2O- (at 110° C.)	.14	1.86	2.01
H_2O+ (above 110° C.)	.69	.64	
TiO_2	1.08	.76	.93
CO_2	None.		
P_2O_5	.49	.20	.41
SO_3		.10	
S	*a*.01		
Cr_2O_3	None.	Trace.	.03
MnO	Trace.	.13	.19
NiO			Trace.
BaO	.10	.15	.13
SrO	.05	Trace.	
Li_2O	Trace.		
	99.68	100.57	100.21

a Undetermined whether sulphide or sulphate.

A. Andesite from Elkhorn Mountain, Elkhorn, Montana. Analysis No. 1858. Field No. 42. H. N. Stokes, analyst.

B. Hornblende-pyroxene-andesite from Sepulchre Mountain, Yellowstone National Park. Contains augite, hypersthene, plagioclase, hornblende, magnetite. Described by Iddings, Twelfth Ann. Rept. U. S. Geol. Survey, p. 633; also in Bull. Philos. Soc. Washington, Vol. II, p. 210; and in Mon. U. S. Geol. Survey, Vol. XXXII, Pt. II. Analysis by T. M. Chatard.

C. Hypersthene-andesite, northwest of Red Bluff, Montana. Contains plagioclase and pyroxene, with an amorphous glassy base and sometimes olivine altered to chloritic matter. Collected by A. C. Peale and G. P. Merrill, Bull. U. S. Geol. Survey No. 168, p. 114.

The analysis shows the Elkhorn Mountain andesite to be of normal character with the exception of the high potash, in this respect showing affinities with the latites of F. L. Ransome, and perhaps having some significance to the later intrusion of quartz-monzonite. In the hand specimen it appears as a dark-gray, almost black, microcrystalline groundmass, in which is sprinkled a small amount of plagioclase phenocrysts that never exceed a millimeter in length. Under the microscope these are found to be very basic, probably corresponding on the average to a bytownite, and to possess on the outer borders a very narrow zone of a rather acid plagioclase. The phenocrysts are original, but the remaining structure of the rock bears marks of the crystallization having been imposed by contact metamorphism, and this is readily explainable when the nearby presence of the batholith and its far-reaching contact effects are recalled.

The groundmass consists for the most part of a mass of feldspar laths from 0.1 to 0.2 mm. in length, while sprinkled like a veil over all the rock, both phenocrysts and groundmass, are flakes of biotite and hornblende. These tend to be confined to strings and patches over the plagioclase phenocrysts, and are taken to show a recrystallization during a period of intense metamorphism, accompanied by a dissemination of the elements of the hornblende and biotite into the cracks of the feldspars.

Crystals of pyroxene are present but are rare, and a little magnetite occurs associated with biotite. Small amounts of analcite and natrolite are found as alteration products. An original faintly marked flow structure still shows. Although this rock has suffered from metamorphism, that action has resulted in no chemical changes, and the small amounts of water present indicate that it has not been altered appreciably by surface weathering. Beds of this character compose the western slopes of Elkhorn Peak, lying stratigraphically above the marbles as well as between them. At the summit the grain of crystallization becomes coarse and the rock is really a microdiorite, though still of the same series.

Lime-rich augite-andesites occur in a number of beds of unusual character on Elkhorn Mountain, consisting of a fine-grained light-gray groundmass, which may or may not contain plagioclase phenocrysts. The light color is due to the absence of all dark minerals, the rock consisting of plagioclase feldspars, orthoclase, zeolites, and colorless beads of augite, the latter indicating a poverty in iron and a richness in lime, and the orthoclase a similar richness in alkalies. The chief significance of these beds is in regard to the possibility of an addition of lime from a sedimentary source, and for that reason they will be fully considered in another paper in connection with that subject and will here be only briefly described. Specimens were taken from two horizons, the lowest, 15 feet in thickness, lying but a few feet above the Mesozoic marbles and lime-silicate rocks at the head of Elkhorn Gulch, thus being near the base of the andesite extrusive series; the second is from a bed 30 feet in thickness lying some distance above the former.

The phenocrysts in the lower bed are of plagioclase, but in the upper are of soda orthoclase, and in both rocks the feldspars have grown through the accession of numerous augite beads without showing any power of exclusion or orientation. The finely granular groundmass consists of feldspar, which is presumably strongly alkaline, together with the augite. Hypersthene is of rare occurrence. Epidote and zeolites are of secondary origin, and quartz is present also, but is probably due to infiltration.

ELKHORN MOUNTAIN LAVAS, BRECCIAS, AND TUFFS.

Between a thick surface flow of lava and a sheet of the same material intruded near the surface it is difficult to discriminate, and for present purposes it is unnecessary to seek to draw the exact line between them. Both are undoubtedly present upon Elkhorn Mountain.

Where the andesite contains brecciated material, either as broken crystals or angular fragments of previously solidified andesite, it may be taken as extrusive in origin. The tuffs consist of a mixture of volcanic dust and angular fragments of lava. When such have become indurated and crystallized the rock is frequently difficult to discriminate from lavas with a devitrified and metamorphosed glassy base holding a breccia.

At the southern limit of the Elkhorn Mountain area the basal beds of the andesite series are tuffs, and over all the southern ridge of Crow Mountain and to the east of Elkhorn Peak, tuffs and breccias are the most abundant rocks. These tuffs have suffered so greatly from metamorphism that at present all are dense, hard, and dark. The breccias show their character on a close examination of the surface, angular fragments being outlined by slight differences in color. The tuffs have a softer and smoother base and in the latter the brecciated material is not so abundant nor so coarse.

Under the microscope the lavas containing brecciated material are seen to be rocks of medium basicity, carrying a good deal of labradorite in broken crystals and fragments of microcrystalline andesites with lesser amounts of siliceous hornstones. The hornstones exist as small angular fragments approaching quartzites in composition, and in polarized light stand out clearly from the matrix.

The andesite fragments, on the contrary, often nearly resemble the groundmass and might readily be overlooked. In none of these breccias are broken fragments of other minerals than labradorite observed, nor in most cases have they formed afterwards from the groundmass. The interpretation to be placed upon this absence of the dark minerals is that at the time of eruption the labradorite crystals were the first to form and were floating as phenocrysts within a molten andesite. Upon eruption the crystals were sometimes blown into the air by the explosive forces of the escaping gases, along with bits of glassy and newly solidified andesite and also of hornstones which had been torn from the strata, these, with the accompanying dust, forming beds of tuff and breccia. At other times the phenocrysts and glassy fragments floated out in the lavas, the latter cooling so quickly that they became either glassy or microcrystalline, thus preventing the formation of other minerals of sufficient size to be identified.

QUEEN GULCH RESIDUAL AREA.

This small area of andesite, only 400 feet wide by 500 feet long, lies on a steep hill slope at a considerable distance from any other occurrence, and 1½ miles directly east of Elkhorn. There are a number of varieties present, but all agree in being rocks with an abundant, finely crystalline groundmass. In certain beds the flow structure is strongly marked, the flow planes dipping S. 55° W. at an angle of 30°. One abundant variety of this rock is so charged with tabular crystals of labradorite averaging three-eighths of an inch in diameter that the waterworn float bowlders are conspicuous in the stream beds for a mile below. Other varieties are dark green and spotted with small crystals of hornblende and labradorite. The forms of the andesite are the same as those noted on Elkhorn Mountain and discussed under the head of "Elkhorn Mountain intrusive andesites," these differing on the whole, however, in being so conspicuously porphyritic.

TURNLEY GULCH ANDESITES.

The edge of this area occupies the southwest corner of the mapped area (Pl. XLV), and forms steep, grassy hill slopes along Turnley Gulch. A sample for analysis was taken in the railroad cut a quarter of a mile south of the limits of the map and 70 feet from the contact with the upper surface of the diorite-porphyry laccolith. The analysis shows somewhat unusual proportions, and is compared with two others which resemble it in some respects, but depart from it in others.

Analyses of andesite and related rocks from Montana and Yellowstone Park.

Constituent.	A.	B.	C.
SiO_2	54.50	53.71	53.75
Al_2O_3	17.97	18.00	20.75
Fe_2O_3	*a*8.55	3.99	4.50
FeO	*b*Undet.	4.05	3.53
MgO	3.37	5.19	3.76
CaO	9.36	6.88	7.18
Na_2O	2.34	3.50	4.16
K_2O	1.62	3.10	1.37
H_2O at 110° C	.14	.55	1.55
H_2O above 110° C	.96		
TiO_2	.94	.74	None
CO_2	None.	....	None
P_2O_5	.31	.38	.15
SO_3	....	....	Trace
Cl	....	....	None
S	.63	....	....
Cr_2O_3	None.	....	....
MnO	Trace.	.24	Trace
BaO	.06	....	....
SrO	.05	....	....
LiO_2	Trace.	....	Trace
	*b*100.80	100.33	100.70

a Contains indeterminable amounts of both pyrite and pyrrhotite, the actual amounts lying between 1.59 Fe_7S_8 and 0.00 FeS_2 and 1.19 FeS_2 and 0.00 Fe_7S_8. FeO can not be directly determined, the 8.55 per cent Fe_2O_3 including the Fe_2O_3 equivalent of FeO and sulphides. The actual FeO lies between 5.39 and 6.46, and the actual Fe_2O_3 between 1.19 and 0.00.

b Summation too high because Fe in FeO and sulphides is stated as Fe_2O_3, the actual excess being indeterminable.

A. Hornblende-andesite-porphyry, altered from an augite-andesite and approaching a basalt in composition, from southwestern part of the Elkhorn district. Analysis No. 1858. Field No. 35. H. N. Stokes, analyst.

B. Mica-gabbro, Hurricane Ridge, Absaroka Range. Contains plagioclase augite, hypersthene, biotite, magnetite, with some orthoclase, and a little quartz and olivine. Described by Iddings in Mon. U. S. Geol. Survey, Vol. XXXII, Pt. II. Analysis by Eakins. See Bull. U. S. Geol. Survey No. 168.

C. Basalt dike, north spur of Mount Washburn, Yellowstone National Park. Reported by Iddings as approaching pyroxene-andesite in composition. Contains labradorite, augite, serpentinized olivine, and magnetite in a groundmass of globulitic and microlitic brown glass. Bull. U. S. Geol. Survey No. 168, p. 110.

The hornblende-andesite-porphyry in A has suffered greatly from alteration, produced in large part by contact metamorphism; but, as shown by the absence of carbon dioxide and the small amount of water present, its composition must closely represent the original. The phenocrysts consist of plagioclase and hornblende. The plagioclases are a labradorite and exist in two forms: (1) The crystals united in clusters up to 2 mm. in diameter, which sometimes show radiating arms, forming fragile and complex crystalline aggregates, and at other times are grouped in clusters without branches, in total amount these crystals form about 10 per cent of the composition. (2) Abundant lath-like crystals, which are from 0.3 to 0.5 mm. long, idiomorphic, and which exhibit a strong zonal structure; these comprise about half of the bulk of the rock.

The phenocrysts contain many inclusions filled with granular hornblende. The form of the inclusion cavities is determined by the feldspar, the cavities being oriented to the crystalline system of the latter. Inclusions of such form in feldspars are of common occurrence in rocks with a glassy base.

Phenocrysts of hornblende or augite have once existed and were of a later growth than the feldspars, but their places are now sometimes filled with granular hornblende of no orientation, suggesting decay of the original mineral and then recrystallization. At other times the hornblende remains in its original system, but the form of the crystals and the character of the rock make it appear clear that the hornblende is a product of uralitization from pyroxene. The groundmass also consists entirely of the same granular hornblende, both brown and green in color. All of these occurrences of this mineral, comprising about 40 per cent of the rock, confirm the impression that the original crystalline character, with the exception of the feldspars, has been entirely altered. Combining the information derived from the microscopic study with that from the chemical analysis, it may be concluded that the rock was originally a glassy pyroxene-andesite-porphyry which approached a basalt in composition. The iron ore, consisting of pyrite and pyrrhotite, with perhaps magnetite, is scattered in granules through the groundmass.

This andesite is quite different in composition from that of Elkhorn Mountain, of which the analysis was given, but the variable character of these lavas has already been pointed out, and the type under consideration is evidently one of the more basic forms, but just to what extent it is typical of all the andesites of this area is difficult to state. Its alteration from contact metamorphism is plainly due to the laccolith which lies immediately below it and of which it formed the cover. The andesites of this area present, on the whole, a much more uniform appearance than those of Elkhorn Peak. Breccias are occasionally observed, but the predominant type consists of an andesite-porphyry, in which the labradorite phenocrysts are usually small and few, but occasionally become a conspicuous feature of the rock. The groundmass is finely crystalline and in some cases has the appearance under the microscope of a devitrified glass.

In the tongue which projects eastward from the main area nearly half a mile and ends in the railroad cut, the rock assumes a coarser crystallization, becoming a microdiorite. A specimen taken from its terminus gives the following mineral composition, estimated by volume under the microscope:

Mineral composition of microdiorite.

	Per cent.
Labradorite	70
Augite	4
Hornblende	8
Biotite	12
Iron ore (magnetite)	2
Quartz	4
Total	100

The labradorite is strongly zonal, an indication of considerable soda within the rock, and the large amount of biotite is a similar evidence of potash. The latter mineral gives the rock somewhat of a kersantitic tendency, and it is principally in that feature that it differs from the dikes cutting the limestone strata on the north and east.

DIORITE-PORPHYRY LACCOLITH.

In the southwestern portion of the district, lying principally in Queen Gulch, is a considerable body of a diorite-porphyry, laccolithic in its manner of intrusion. Its bottom is the isolated fragment of Starmount lime-silicate rocks, forming a plane dipping 42° to the southwest, the dome-like cover consisting of andesites which have been partly removed by erosion. The bottom of Elkhorn Gulch at its junction with Turnley Gulch is cut well down into it, but the principal exposure is in Queen Gulch, where it attains a thickness perpendicular to its walls of 1,300 feet.

The rock presents a conspicuous appearance, consisting of about 30 per cent of labradorite phenocrysts and several per cent of biotite and hornblende, the latter two minerals in clusters, giving a spotted and mottled surface. The phenocrysts are embedded in a fine-grained crystalline groundmass, gray in color.

Under the microscope the rock is seen to strikingly resemble that composing the laccolith of Steamboat Mountain in the Little Belt Mountains, Montana.[1]

No analysis was made of this rock, and in default its mineral composition by volume is given as estimated by the microscope. While the percentages are, of course, not exact, the character of the rock is clearly indicated.

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[1] Geology of the Little Belt Mountains, by W. H. Weed, with report on petrography by L. V. Pirsson: Twentieth Ann. Rept. U. S. Geol. Survey, Pt. III, 1900, pp. 333, 515.

Mineral composition of rock of diorite-porphyry laccolith.

	Per cent.
Labradorite	33
Biotite	3
Hornblende	3
Pyroxene	.3
Apatite	.3
Iron ore	1
Groundmass:	
Quartz	10
Plagioclase	20
Alkaline feldspar	30
Total	100.6

The composition of the feldspars of the groundmass is necessarily estimated with some uncertainty. To describe the peculiarities of the minerals more in detail: The feldspar phenocrysts are from 1 to 4 mm. in diameter and show a very strong zonal structure. The greater part is a rather basic labradorite, varying from $Ab_1\ An_2$ to $Ab_3\ An_4$, intergrown perthitically with an andesine. Over the parts which are intergrown the extinction is constant. After a certain time in the period of growth, however, the residual liquid could not or did not supply any longer the more basic feldspar molecules, and then the period of zonal growth began, the composition of the added shells of feldspar passing from andesine to oligoclase, and from the latter to albite, the extension of the lines of albite twinning to the extreme boundaries proving that no monoclinic feldspar exists in the outer zones. The noticeable feature of the zonal growth is its wide range and large amount, running as it does through nearly the whole series of the plagioclase feldspars. The transition is not always regular, a more basic zone sometimes surrounding one slightly more acid. Some of the feldspars contain many small inclusions within the labradorite interior, consisting of an acid plagioclase with a nucleus of hornblende, probably resulting from the rapidly growing crystal inclosing small portions of the magma which finally crystallized into the feldspar and hornblende.

The biotite is older in formation than the hornblende. With the latter it is collected into irregular clusters containing the iron ore and apatite also, and giving the dark, spotted appearance to the rock.

In one instance a well-bounded prismatic crystal of hornblende is observed, 5 mm. long and quite different in outline from the ragged crystals normally present. This prism has nuclei of brown hornblende throughout, surrounded by green hornblende possessing the appearance of an alteration product. Such a difference in habit in the same thin section between crystals of the same species may be taken as evidence of growth under different physical conditions, and this may be an instance of a hornblende phenocryst formed before intrusion, in contradistinction to the others formed afterwards.

Pyroxene is sparsely present, occurring in small, colorless, anhedral crystals associated with the apatite, and sometimes present as inclusions within the feldspars.

The feldspar of the groundmass embraces about 50 per cent of the entire rock. In so far as it can be separated it consists of about 40 per cent of small plagioclase crystals, showing either a rod-like form or chunky crystals with lines of albite twinning. Another 40 per cent of this groundmass feldspar consists of somewhat dusty, chunky crystals showing no albite twinning and taken to be orthoclase. The other 20 per cent is orthoclase intergrown with quartz and forming a well-developed micrographic structure.

The basic character of the phenocrysts in this rock is to be noted, standing in contradistinction to the rather acid character of the groundmass, and from a consideration of the former alone a very erroneous idea of the composition would be obtained.

TURNLEY RIDGE STOCK.

The Turnley Ridge stock is a very irregular and branching intrusion running for about two miles across the southwestern corner of the district and varying in width from several hundred feet to a half mile. In its northern part it consists of two arms, which hold a series of altered shales and quartzites between them.

The surface débris, by which it may be readily recognized, consists of angular blocks a foot or more in diameter, of a chalky color where not stained light brown and red from ferric oxide. It is a rock readily susceptible to weathering without disintegration, yielding surface material rather light in weight and giving a dull sound when struck with the hammer. A feature by which the rock may be recognized consists of numerous crystals of quartz, a tenth to a twentieth of an inch in diameter, scattered through the groundmass. These not being subject to the subaeriel decay which attacks the other minerals, show the greasy quartz luster and irregular fracture and are readily noted upon a close examination of the hand specimen. Besides the quartz crystals, which form about 15 per cent of the volume, the rock contains about 40 per cent of rectangular crystals of oligoclase, weathered to a chalky white. In favorable situations, as in the deep railroad cut on Elkhorn Gulch, material may be obtained which has not been affected by weathering. On such a fresh unweathered surface the groundmass, which composes about 40 per cent of the entire volume, is seen to be dense and of a light-gray color. Even where unweathered, however, the feldspar phenocrysts are dull and lusterless. A microscopic examination shows that the rock has been greatly altered by mineralizing waters, which have not only given this appearance to the feldspars, but have utterly destroyed the several per cent of dark minerals which were originally present, and have finally resulted in the formation of considerable pyrite. A partial analysis of a specimen as nearly unaltered as could be found, taken from the railroad cut 6,000 feet south of the Elkhorn station, gave the following results:

Partial analysis of quartz-diorite-porphyry.

[H. N. Stokes, analyst. Rec. No. 1858. Field No. 7.]

	Per cent.
SiO_2	67.44
Al_2O_3 (including P_2O_5)	16.79
Fe_2O_3 (total iron)	2.10
Na_2O	4.19
K_2O	4.20
H_2O	1.48
LiO_2	Trace.
Total	96.20

Allowing for the destruction of the ferromagnesian minerals and taking the average of a number of sections, the original mineral composition has been estimated by volume as follows:

Mineral composition of quartz-diorite-porphyry.

	Per cent.
Oligoclase	40
Quartz	15
Hornblende	2
Biotite	2
Groundmass (quartz and feldspar)	41
Total	100

There is usually a sharp distinction between the phenocrysts and groundmass, the latter being a microgranitic mixture of quartz and feldspar, the former possessing sharp idiomorphic boundaries several millimeters in diameter, though certain of these may be cleavage faces and not those once terminating the crystals. The feldspar phenocrysts possess an average diameter of 2 mm., usually show albite twinning, and range in chemical composition from a sodic labradorite to albite. Orthoclase is present in some parts of the intrusive and may form a minor part in others. Oligoclase, however, is the common type of the feldspar phenocrysts.

The quartz phenocrysts average 1 to 2 mm. in diameter, exhibiting, when unbroken, straight crystalline sides rounded on the corners. Their principal growth took place before the intrusion into the present locality, since many fragments show a crystalline outline on one side and an irregular fracture on the other, and sharp fragments, the débris of broken and dragged crystals, are common. The extinction is sharp and not undulatory, showing that the fracture has not been accompanied by great stresses. This is to be expected, since in a viscid medium a body would be pulled apart or sheared rather than crushed with straining of the crystallographic orientation. In most places considerable solution of the quartz, sometimes resulting in smooth, gibbous forms, has taken place after the crystals came to rest and before the final solidification. Upon the crystallization of the groundmass the small particles adjacent to the quartzes have oriented themselves against them, giving, when seen under a high power, a fine-grained, serrated margin. Within the tongue on the southern side no quartz phenocrysts are found, a fact worth noting, considering the evidences elsewhere that the quartzes are older than the intrusion. It may be due to the tongue being filled by material of the first advance which was retained there, while elsewhere within the stock the present rock may perhaps represent later accessions which alone contained the crystals of quartz.

The biotite has been completely resorbed by later processes, there remaining within the original outlines a sprinkling of microgranitic feldspar with small grains of iron ore and flakes of biotite. Certain sections show fairly numerous splinters of hornblende, but these, occurring especially within the feldspar phenocrysts, have the appearance of being of secondary origin, and that which remains as an original component is probably rare.

There is abundant muscovite, especially near the contacts, scattered over the section and resulting from alteration of the feldspar. The appearance is quite different from the dust-like flakes of kaolin which have resulted especially from surface weathering. In this rock the muscovite is sharply bounded, transparent, and scattered over the whole section through phenocrysts and groundmass, leaving clear and transparent those parts of the feldspars not occupied by it.

BATHOLITH AT ELKHORN.

The rock of the batholith occupying the northwestern quarter of the district is not uniform over large areas, but in places assumes a granitic phase, and, especially near the margins, often becomes a diorite. Predominantly, however, it is a quartz-monzonite with the field appearance of a dark granite. An article dealing with the general characteristics of the rocks of the batholith and embracing a study of the analyses made from various places has been published by Weed,[1] and consequently but little need be said here upon that topic.

For purposes of analysis, material was collected on the western margin of the district, a mile from the contact with the sedimentary formations. The analysis shows a very close agreement with that of the Butte granite and also with that from Clancey Creek, but is somewhat more basic than the prevailing type of the Boulder granite.

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[1] Granite rocks of Butte, Mont., and vicinity, by W. H. Weed: Jour. Geol., Nov.-Dec., 1899, p. 737.

The analyses from those localities are brought together for purposes of comparison.

Analyses of rocks from the Boulder batholith.

	112.	6 (*a*).	98 (*a*).	518 (*a*).
	Per cent.	*Per cent.*	*Per cent.*	*Per cent.*
SiO_2	64.31	64.05	64.17	67.12
Al_2O_3	15.44	15.38	15.25	15
Fe_2O_3	2.43	2.20	2.16	1.62
FeO	2.58	2.74	2.98	2.23
MgO	2.21	2.08	2.60	1.74
CaO	4.22	4.30	4.24	3.43
Na_2O	2.71	2.74	2.62	2.76
K_2O	4.09	4.00	4.34	4.52
H_2O at 110° C	.19	.83	.65	.58
H_2O above 110° C	.79	.27	.16	.09
TiO_2	.71	.60	.67	.48
CO_2	None.	.35	None.	None.
P_2O_5	.22	.21	.16	.15
SO_3			.97	Trace.
Cl			Trace.	
S	*b* Trace.	.07		
Cr_2O_3	None.			
MnO	Trace.	.11	.04	.06
BaO	.07	.08	.07	.07
SrO	Trace.	.04	Trace.	.03
Li_2O	Strong trace.			
Total	99.97	100.05	100.18	99.88

a Granite rocks of Butte, Mont., and vicinity, by W. H. Weed: Jour. Geol., Nov.-Dec., 1899, p. 737.
b Whether S or SO_3 undetermined.

No. 112. Type of the batholith at Elkhorn, 1 mile from the contact.
No. 6. Butte type of granite, Butte district; H. N. Stokes, analyst.
No. 98. Head of Clancey Creek, northern part of batholith; H. N. Stokes, analyst.
No. 518. Prevailing type of granite of batholith at Boulder; H. N. Stokes, analyst.

The rock whose analysis is given under 112 resembles the Butte granite as closely in appearance as it does in chemical composition. It is a rather cross-grained rock, showing about equal amounts of hornblende and biotite, quartz existing in smoky grains and the feldspars with gray to pink cleavage surfaces. Under the microscope the plagioclase is seen to range from an andesine, $Ab_5\ An_4$, to a sodic labradorite, $Ab_1\ An_1$, existing in idiomorphic but not well-formed crystals from 1 to 3 mm. in diameter. The orthoclase and quartz are, as usual, the final products of crystallization, the former containing some soda. The apatite, magnetite, augite, hornblende, and biotite are associated together, the apatite being the earliest mineral to crystallize, then the augite, the latter forming very irregular nuclei in the interior of many hornblende crystals. The hornblende preceded the biotite in crystallization, and the formation of these three minerals resulted in the simultaneous separation of magnetite. The latter exists in grains averaging a third of a millimeter in diameter and also as a dust sprinkled through certain of the hornblendes. The small amount of titanite present belongs also to the earliest mineral generation.

Variations in texture.—The rock of the batholith varies both in texture and in composition. The type which was analyzed is rather coarse grained and without any evidence of gneissoid or flow structure. At other places not far distant, however, and forming a type perhaps equally abundant, the rock, without changing noticeably in composition, shows a faintly parallel arrangement of the dark minerals, which gives it a somewhat gneissoid structure. This variety does not show any intimate relation to the contact, though perhaps more abundant within a mile of it. In the vicinity of the contact, and forming a zone of variable width, the rock becomes finer grained, though no case has been observed within the district, or elsewhere at the margins of the batholith, where a distinct porphyritic structure is assumed.

The principal effect of the contact has been to cause a more or less simultaneous growth of the minerals, which gives an approach to the sugar-granular structure, and the quartz and orthoclase are also sometimes poikilitically interwoven.

Variations in composition.—The lamprophyric facies are not so strongly marked as is frequently the case, but still are noticeably present. Throughout the entire contact and for distances of a quarter of a mile from it the rock usually shows a greater predominance of plagioclase, and often of ferromagnesian minerals. These contact facies may be hardly noticeable to one traveling over the country, but become evident upon comparing specimens from different points, the transition being by a shading of one type into another and not by marked contrasts.

The limits of the variations are brought out in the table of comparisons on the next page, the rock from four points along the contact being compared to that of which the analysis has been given. The rock never becomes more basic than a diorite, and the amount of dark components is not greatly increased. Slight differences in composition, however, may in some cases cause hornblende to become the ruling species, and at other times biotite. The most constant differences on approaching the contact lie in the increase of plagioclase and the decrease of quartz, indicating a rise in alumina and a fall in silica.

At other places on the margins of this batholith, where contact facies approaching the gabbros have been observed, they have been often found in bays entering into the sedimentaries, and the absence of such within this district, at least in evident connection with the parent batholith, may be the reason for their failure to occur. The analyses[1] of two such forms from Red Mountain, 10 miles south of Butte, show 49.22 and 56.41 per cent of silica, respectively.

The table shows the mineral composition by volume as estimated by the microscope, a method sufficiently accurate to bring out the general variations which are under discussion.

Varieties of granitic rocks of the Boulder batholith within the Elkhorn district.

	112.	138.	56.	164.	38.
Labradorite, $Ab_1 An_1$	34	49	40	62	40
Andesine, $Ab_5 An_3$					15
Orthoclase with Na_2O	22	10	30	5	20
Quartz	25	10	16	15	5
Biotite	7	21	8	18	1
Hornblende	9	7	5		17
Augite	2	2			
Magnetite	1	1	.5		2
Apatite	.3	.1	.1	.1	.1
Titanite	.5		.1		
Rutile			Trace.		
	100.8	100.1	99.7	100.1	100.1

No. 112. Quartz-monzonite. Type of batholith, 1 mile from contact, on western limit of map. See analysis on page 536.

No. 138. Diorite. From batholith. Originally, perhaps, 100 feet from contact with limestones; at present separated by aplite dike 400 feet wide. From point 2,500 feet north of Black Butte triangulation point.

No. 56. Quartz-monzonite, rich in feldspar; 100 feet from contact with andesite; northeast corner of map.

No. 164. Quartz-mica-diorite; 20 feet from contact with hornstone inclusion; half mile southwest of Black Butte triangulation point.

No. 38. Diorite; 50 feet from the quartz-diorite-porphyry stock of Turnley Ridge: on western limit of map 1 mile north of southeast corner.

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[1] Granite rocks of Butte, Mont., and vicinity, by W. H. Weed: Jour. Geol., Nov.-Dec., 1899, p. 739.

APLITES.

The aplites, as the term is commonly understood, are rocks of a sugar-granular texture due to a fine-grained, simultaneous crystallization of quartz and orthoclase, the rock consisting of those components with little or no ferromagnesian minerals. The term is ordinarily limited to sheets or dikes intrusive in granitic rocks and regarded as acid segregations from the original magma. In the larger masses the normal texture may fail and the rock become granitic, so that the intrusive nature and the intimate relationship with the main granitic mass must be relied upon as the final test.

The usual form of their occurrence in the area of the batholith is as thin dikelets a few inches in width, fairly numerous, with sharp, even contacts, and traceable for some distance. Where one terminates there is often an offset and the line is extended by another dike a few feet to one side. The texture is fine grained and of the sugar-granular type.

More abnormal forms of occurrence are as flat, lens-like masses, as at Butte,[1] but not found within the Elkhorn district, or as dikes several hundred feet in width with a granitic texture and parallel to the contact, as at Elkhorn. The chemical composition, as well as the texture, shows considerable variation, so that the basic varieties of the aplites may approach the acid forms of the original batholith intrusion, and the only safe criterion for discrimination lies in a study of the contact, the acid forms of the original magma passing into other varieties by gradations, while the aplites always show sharp contacts and evidences of later intrusion. The aplites are commonly believed to be acid segregations out of the original magma, here a quartz-monzonite, and it is supposed that their intrusion immediately followed the solidification of the greater parts of the bathol th.

The aplites of the Elkhorn district occur as thin seams over most parts of the batholith area, but near the margins, as previously mentioned, they become dike-like intrusions of great volume. Analyses were made from the center and near the contact of that one which has broken through the quartz-monzonite north of Black Butte and which covers the greater part of the area for a quarter of a mile in width. The analyses show that the outer parts of the intrusion are more basic than the center, but are still clearly aplites. The chemical composition is remarkably similar to that of the Butte aplites, situated in the same batholith, but at a distance of 33 miles to the southwest, corresponding to a like similarity which was pointed out as existing between the quartz-monzonite of the two districts.

The resemblance of these types to the granodiorites and granulites of the Sierras has been pointed out by Weed.[1] An analysis of one of the Sierra granulites (aplites) is added for purposes of comparison.

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[1] Description of the Butte Special district, by W. H. Weed: Geologic Atlas U. S., folio 38, 1897.

Analyses of aplites from Montana and California.

	109.	142.	640.	192.
SiO_2	76.26	74.61	76.87	75.97
Al_2O_3	12.94	13.36	12.52	13.07
Fe_2O_3	.69	.83	.67	.61
FeO	.13	.36	None.	.39
MgO	.17	.35	.09	.14
CaO	1.10	1.35	.49	1.49
Na_2O	2.73	2.49	2.47	2.51
K_2O	5.26	5.70	5.78	5.62
H_2O at 110° C	.17	.19	.52	.24
H_2O above 110° C	.43	.42	.25	.14
TiO_2	.11	.11	.11	.09
CO_2	None.	None.		
P_2O_5	.06	.06	.05	Trace.
S	[a] .01	[b] Trace.		
Cr_2O_3	None.	None.		
NiO	None.			
MnO	Trace.	Trace.		Trace.
BaO	.07	.10		.14
SrO	None.	Trace.		Trace.
Li_2O	Trace.	Trace.		Trace.
Total	100.13	99.93	99.82	100.44

[a] Total S. [b] Whether sulphide or sulphate undetermined.

No. 109. Aplite from middle of large intrusion, 1,000 feet west of batholith contact, north of Black Butte. Analysis No. 1858. Field No. 109. H. N. Stokes, analyst.

No. 142. Aplite from eastern side of same intrusion, near inclusions of quartz-monzonite, 2,500 feet north of Black Butte. Analysis No. 1858. Field No. 142. H. N. Stokes, analyst.

No. 640. Aplite of Butte granite, Butte, Mont.

No. 192. Granulite (aplite) dike east of Milton, Sierra County, Cal. Collected and described by H. W. Turner. W. F. Hillebrand, analyst. See Bull. U. S. Geol. Survey No. 168, p. 192.

In general the aplites of the Elkhorn district show the sugar-granular texture and consist of soda orthoclase and quartz, with a few per cent of plagioclase and occasional crystals of biotite and magnetite. The plagioclase is an andesine and is idiomorphic; the quartz and orthoclase, however, have grown simultaneously and neither has been able to assume its proper crystallographic form.

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[1] Granite rocks of Butte, Mont., and vicinity, by W. H. Weed: Jour. Geol., Nov.-Dec., 1899, p. 740.

The biotite usually forms from one-half to 2 per cent, and occurs in thin scales averaging 0.3 mm. in diameter. The lack of clustering in the biotite is characteristic and gives a finely speckled appearance to the rock.

ELKHORN MOUNTAIN APLITE.

The above petrographic description applies entirely to the northernmost intrusion, a thick sheet lying between the quartz-monzonite and the andesites of Elkhorn Peak. The aplite in its contact against the andesite forms a sharp and even surface and shows evidence of chilling against the latter rock. At the immediate contact a zone of aplite an inch in width is fairly coarse grained, with quartz and feldspar poikilitically intergrown and possessing a considerable amount of biotite. This coarseness is evidently due to the contact surface offering a passage for the escape of vapors, whose influence in inducing a coarser crystalline structure is well known.

Following the narrow band of coarse-grained aplite is a zone several feet in width with an indefinite inner boundary characterized by a radiate poikilitic intergrowth of quartz and orthoclase, the mixed grains being 2 mm. in diameter. There is much less biotite than at the immediate contact. A thin section taken 52 inches from the contact showed certain crystals of orthoclase which became poikilitic only after half their growth was completed, indicating a change in the physical conditions at that period, owing to which the quartz and orthoclase could no longer separate themselves from each other during crystallization, and were of simultaneous growth. At a distance of 20 feet the aplite shows its normal sugar-granular character.

The importance of these contact phenomena lies in the proof they furnish that the aplite is younger than the andesite.

The aplite stock.—In the aplite stock penetrating the sediments 6,000 feet southwest of Elkhorn Peak the aplite structure is nearly lost and the rock assumes the appearance of an acid granite. It has no visible contact with the quartz-monzonite and consequently its aplitic affinities are based solely upon its mineral and chemical composition. The change in texture is no doubt due to the large diameter of the stock, which permitted a thorough heating of the walls and a prolonged period of crystallization.

APLITE DIKES NORTH OF BLACK BUTTE.

In the system of dikes which have broken through the quartz-monzonite lying north and west of Black Butte, the normal type of aplite is that given in analysis 109, on page 540. It is an acid granite, with but little biotite and but little of the sugar-granular texture. It shades into two prominent varieties, one of which approaches the pegmatitic, the other the porphyritic type of structure. The former occurs at places in the center of the intrusions, and one locality was noted where the biotite showed a great extension along one of the horizontal axes, forming thin blades, half a millimeter in width by 12 to 15 mm. in length. The other variety is found near the margins of the intrusions, an analysis of it being given as No. 142, on page 540. It is finer grained, shows the typical aplite structure, and is richer in biotite, the latter existing in scales and not in clusters. Within the immediate vicinity of the margins, however, clusters are formed which resemble those of the quartz-monzonite.

APLITE DIKES SOUTHWEST OF BLACK BUTTE.

The aplites occurring at intervals along the margin in the southern part of the district show the normal character, except at one locality half a mile southwest of Black Butte, where phenocrysts of a soda orthoclase, an inch in diameter, are abundant. The crystals are poikilitically intergrown with quartz, which is visible in wavy lines to the naked eye and constitutes about a quarter of the volume of the crystal. By the exclusion of the biotite and plagioclase molecules from the area of the phenocrysts, the aplitic groundmass is correspondingly enriched in those components.

CONTACT DIKES OF APLITE IN TURNLEY GULCH.

A few dikes of aplite cross Turnley Gulch, barely within the limits of the map. They are of medium width, and lie between the quartz-monzonite and the andesite. Stringers from them penetrate the andesite and prove in the most unequivocal manner the younger age of the aplite, and therefore also of the quartz-monzonite. This deduction gives them great importance, and hence one is illustrated in Pl. LXII, *B*.

SEGREGATIONS OF TOURMALINE.

At a number of places within the aplites, especially on the road to Elkhorn Peak, at an elevation of about 8,000 feet, and near the borders of the intrusions north of Black Butte, crow-foot segregations of a black mineral are observed. These are usually about 1 inch in diameter, but may be from 4 to 6 inches across. Sometimes they are irregular, dendritic forms, at other times circular or rhomboidal in outline. The segregations are intermixed with quartz and orthoclase, and under the microscope are found to consist of a dark tourmaline, without crystal boundaries. The tourmaline areas are always surrounded by a white zone from one-half to 1 inch in width, from which the dark components have evidently been exhausted, beyond which the aplite assumes its normal appearance and possesses its scales of biotite. The boron and fluorine of the tourmaline, indicative of pneumatolitic action, and especially associated with contact surfaces, have combined with the constituents which otherwise would have formed the mica, and the width of the white zone marks the power of migration which the molecules have shown in coming together to form the segregations.

ALTERED SEDIMENTARY (CONTACT-METAMORPHIC) ROCKS.

USE OF NAMES.

For the results of contact metamorphism there is a lack of generic and specific names, as most of the names which are applied to metamorphic rocks denote species which have been subjected to dynamic action, and which differ conspicuously in appearance from those formed by the contact action of heated masses without the superimposed effects of deformations. Of the names used more particularly in describing the results of contact action "quartzite" has a definite meaning, being applied to a metamorphosed sandstone which, to make a typical quartzite, should be fairly free from lime or alumina. "Hornfels" is used as a rather general term to include the metamorphosed products from shales, slates, or clays. The word "hornstone" is nearly equivalent, but is also applied to flint or chert, and its use is therefore objectionable. "Marble" is the result of metamorphism of a rather pure limestone.

Taking the three predominant constituents of the sedimentary rocks as lime, alumina, and silica, it is seen that for the various metamorphosed admixtures of the three, forming very diverse rocks, there are no good group names, and there is a poverty of those having specific value. On dividing the sediments into five chief groups according to their composition, the following names are seen to apply:

Composition.	Name.
1. Silica	Quartzite.
2. Silica-alumina	Hornfels, or hornstone.
3. Silica-lime	Lime-silicate rock.
4. Lime-silica-alumina	Lime-alumina-silicate rock.
5. Lime	Marble.

Since alumina does not occur in rock masses except in association with silica, there are no alumina or lime-alumina groups.

To eliminate as much as possible the rather clumsy term of lime-alumina-silicate rock, the name of the predominant mineral may be employed as an adjective. Thus one may speak of a grossularite,[1] a vesuvianite, or a labradorite rock, as the case may be.

The metamorphosed sediments will be treated in groups according to composition, and not chronologically, the divisions being taken up in the order in which they have just been named.

QUARTZITES.

PURE QUARTZITES.

The pure quartzites are grayish-white rocks, finely granular and having a vitreous luster upon fresh fracture. The purest beds within the Elkhorn district are found within the Quadrant quartzites and at the top of the Cambrian quartzite.

From this pure type, which is relatively rare, there are departures in several directions. Small amounts of kaolin, orthoclase, and undecomposed rock are commonly present in the original sandstone as a clay-like filling, and upon metamorphism these turn into biotite and feldspars. On the other hand, there may be soluble materials within the sandstone, and their removal and the presence of silica-bearing waters may result in a further deposition of silica and ally such replacement quartzites to the vein quartzes.

QUARTZITIC HORNSTONES.

Those metamorphic rocks which approach most nearly to the quartzites, but differ from them in having originally possessed an admixture of clay and undecomposed rock fragments, are dark in color and present the appearance of a finely granular eruptive rock. Examples of this type are found in the middle member of the Turnley series, originally a fine-grained shaly sandstone. The rocks now consist of about 15 per cent of olive-green flakes of microscopic biotite and 85 per cent of quartz. The color is due to the dark mica, and the fracture is somewhat sugary, from the great abundance of quartz (field No. 22).

The greatest coarseness of crystallization in rocks of this composition is observed in those places where they are adjacent to the granite. One such (field No. 4) under the microscope was found to consist of 70 per cent quartz, 10 per cent acid plagioclase feldspar (probably all oligoclase), and 20 per cent deep-brown biotite in plates up to half a millimeter in length. The crystals show the mutual indentations due to simultaneous growth, a feature characteristic of quartzites and hornstones, and the carbonaceous matter is scattered dirtily through the feldspars. The most typical representatives of this group of metamorphosed sediments are found within the Mesozoic, where they show as hard, prominent ledges which only the trained geologist could with certainty distinguish from eruptive rocks.

---

[1] Grossularite is a lime-alumina garnet; it varies greatly in color, but in the Elkhorn rocks is usually pale brown, or, more rarely, green. Vesuvianite is a basic lime-alumina silicate, carrying ome iron.

A bed of dark, coarsely granular rock which should also be grouped under this heading was noted in the Turnley shales, the lowest sedimentary horizon of the district (field No. 20). Under the microscope it is seen to consist of extremely irregular anhedrons of quartz and feldspar from 1 to 2 mm. in diameter. The feldspars are predominantly alkaline and are very irregular in composition, giving an uneven extinction under crossed nicols. Unlike the other quartzitic hornstones, the crystal individuals are not clearly separated from one another, but show extensive intergrowth. The biotite crystals show the form characteristic of hornstones and are scattered through the feldspar, sometimes composing half the volume, in other places existing in clusters. The uneven distribution of the biotite causes the rock, when seen in plain light in thin section, to resemble an arkose, but such an appearance may be an effect of crystallization. There is considerable groundmass, mostly of a feldspar.

The greater freedom of crystallization which this rock shows may be due to its being a stratum readily permeable to rising vapors.

HORNSTONES.

The hornstones, as the name is here used, include those metamorphosed rocks that are rich in silica and alumina—rocks which in their original state belonged to the clay series. They always carry with the alumina a considerable amount of alkalies, lime, magnesia, and iron, and upon reconstitution consist predominantly of quartz, biotite, and feldspar, the character of the rock changing with the relative amounts of each and the coarseness of crystallization.

Those hornstones rich in argillaceous matter are much softer, and in the field may resemble argillaceous limestones. The content of lime, however, has always been low, and in their metamorphosed state they never effervesce with acid. They have been originally shales, and the two great changes which have taken place are a loss of the fissile nature and often a marked change in color, the latter being due to a clearing up of the groundmass through crystallization into feldspars or quartz, the collection of the organic matter in dots affecting the color less than if disseminated, and, lastly, the color given by microscopic biotite flakes set up throughout the section. The Union shales show these differences well, since north of the town they exist with their original black fissile character, but on the southern side of the Cemetery Ridge stock they are soft rocks of a purplish-red color (field No. 10), without much cleavage, and with a fine-grained splintery fracture. Under the microscope this hornstone is seen to consist of the following components:

	Per cent.
Light-brown biotite flakes	25
Quartz grains	4
Graphitic pigment, in opaque strings and grains	2
Microgranitic feldspar and quartz groundmass	69

The lowest member of the Turnley series is a somewhat similar hornstone, of a lighter purplish red, consisting of 33 per cent of biotite flakes and 67 per cent of finely granular quartz. Its fissile character has not been entirely destroyed. Within the Mesozoic series similar beds are found, one being noted of a slate-blue color.

LIME-ALUMINA-SILICATE ROCKS.

The lime-silicate and lime-alumina-silicate rocks are of great hardness, and in color range from white to pale brown, green, or yellow. They indicate their large percentage of lime by showing under the microscope essentially the lime-silicate minerals. Usually not more than three such minerals constitute the bulk of any one rock, though the species vary according to the composition of the strata. Those of commonest occurrence are grossular-garnet, diopside, wollastonite, vesuvianite, and lime-soda feldspars.

Wherever the strata are of the proper composition they may be metamorphosed bodily for distances of several hundred feet from the igneous contacts, with the formation of certain of these minerals and the expulsion of the carbonic acid.

The Starmount argillaceous limestones are the lowest strata of this character. South of Black Butte, and extending from there to Elkhorn Gulch, they are seen in occasional outcrops, and at other places are exposed by erosion of the soil. The bedding planes are still evident, but the rocks are hard, and sometimes show coarse crystals of pale-green diopside, at other times pale-brown garnet in banded lens-like masses or in sponge-like growths. South of Elkhorn Gulch there is but little metamorphism within the main mass of sediments, but within the fragment isolated between the quartz-diorite-porphyry and the diorite-porphyry laccolith the final degree has been reached.

The impurities of the strata have been sufficient to combine with all the lime, completely expelling the carbonic acid.

The average composition of these rocks is about as follows:

	Per cent.
Grossularite	45
Diopside	20
Wollastonite	10
Lime-soda feldspar	10
Alkali feldspar	15

The next horizon showing great alterations of this character is that of the Keene limestones at their contacts with the Cemetery Ridge stock. These rocks being less argillaceous than the Starmount limestones, the garnet sinks to a subordinate amount and the siliceous impurities combine with the lime and magnesia, predominantly as a pyroxene and no doubt approaching a pure diopside in composition. That the silica of the Keene metamorphic rocks was not derived from the neighboring magma is indicated by the contact on the northern side of the stock against the Madison limestones. Here the limestone, being free from impurities, exists still as a carbonate rock to within a foot or so of the contact.

A large part of the Mesozoic hornfels series, as is shown in the detailed section given elsewhere, consists of metamorphosed strata belonging to the lime-alumina-silicate group.

LIME-SILICATE GROUP.

The simplest case for study is that of a limestone containing a small amount of silica. This type is not uncommon, since it is seldom that the marbles are absolutely pure. A thin section from a marble inclusion within the quartz-monzonite (field No. 133) showed under the microscope about 5 per cent of wollastonite and 4 per cent of another mineral decomposed to a white amorphous product.

The section is instructive as showing the manner of formation of the metamorphic minerals when they are few in number and therefore not restrained in their growth by other individuals of the same species. Ninety per cent of the rock consists of irregular anhedrons of calcite, averaging from one-half to 1 mm. in diameter, and containing many very minute scales, about 0.01 mm. in size, whose nature is not determinable. Wherever calcite has been observed in the metamorphic rocks of this district it is always allotriomorphic and the minerals projecting into it often show their proper crystalline form.

The wollastonite occurs scattered evenly over the section, the chunky prisms averaging a millimeter apart and a third of a millimeter in length. The extension is in the direction of the cleavage. Although the opportunities for free growth have here been exceptional, the wollastonite crystals do not possess well-formed faces but have all the corners smoothly rounded off, presenting a resemblance to waterworn pebbles. In their isolation from one another and opportunities for free growth, these crystals are analogous to the minerals of earliest generation within a magma, and their subidiomorphic outlines may be a characteristic of their metamorphic origin. In regard to wollastonite it must be said, however, that it is not a mineral of the earliest generation, since where it occurs in the presence of augite it exists as a cement to the latter mineral. When growing within a marble it may not assert itself with the same power as do some other minerals, notably garnet.

In the Keene limestones, at their contact with the Cemetery Ridge stock, as before noted, the original rock is a siliceous dolomite which upon metamorphism becomes a diopside rock, though probably containing some alumina. The diopside where existing free, either in calcite or in wollastonite, shows as clear, elongated, spheroidal beads, often not more than .01 mm. in diameter. Where it forms the bulk of the rock it exists as anhedrons rudely fitted together and without sharp corners. The usual size of the individual grains in such aggregates is about .05 mm., though sometimes they are much coarser.

ORDER OF CRYSTALLIZATION OF THE MINERALS OF THE LIME-ALUMINA-SILICATE GROUP.

When metamorphosed the rocks belonging to this group indicate their character by the presence of some lime-aluminous minerals, such as garnet, vesuvianite, epidote, and plagioclase. Although these rocks, like the hornstones, usually show a mutual restraint among all the minerals, yet certain species often exhibit somewhat idiomorphic outlines and indicate a definite order in crystallization.

Garnet is the mineral which oftenest has power to assume its proper form, and does so in the presence of all the other minerals. Augite, while molded by garnet, itself molds wollastonite (field No. 27). Calcite is often a secondary mineral, and in such cases fills miarolitic cavities or replaces some previous mineral, and is naturally in such cases highly allotriomorphic.

Where existing evidently as an original mineral (field Nos. 9, 146) it forms either a background for small crystals of other minerals, such as beads of augite, or exists itself in globular masses as inclosures within other minerals. It is never seen to assume its crystallographic outlines.

Occurrence of minerals.—The combination of species is determined to a great extent by the proportionate amounts of the elements in the rock, but besides this there are certain minerals which show a greater tendency to form than do others. Garnet is the most universal of these and is very common wherever the alumina and silica exist in proper amounts.

Where the garnets occur of microscopic size they do not show the sharp angles customary in larger specimens, but are of a roughly polygonal form. The usual size of the grains in the thin sections is from .05 to .10 mm., and where existing in considerable areas the grains are gathered together in mulberry-like clusters.

Vesuvianite is comparatively rare in the Elkhorn district. Its chemical composition is near to that of grossularite, and the latter, under the conditions prevailing in this region, has usually been the mineral species with strongest tendencies to form.

Where the composition of the original rock determines the formation of feldspars as a metamorphic product, these usually assume the form of anhedrons about .05 mm. in diameter, crowding one another closely and entirely allotriomorphic, forming a groundmass whose appearance is unlike that of an igneous rock. Microcline has been noted in larger areas, 1 mm. or more in diameter, the crystals showing watered effects, fitting against one another by irregular margins and including within them fragments of the other minerals (field No. 169). Such areas strongly resemble the occurrence of microcline in some syenites, and nothing but the field relations and appearance of the hand specimen decide as to whether the rock was originally igneous or sedimentary.

The most general distinction between the rocks of igneous and sedimentary origin lies in the usual allotriomorphic character of all the minerals composing the latter.

The mineral species are usually also distinct, and where alike occur in different percentages characteristic of the two classes. There are cases, however, where rocks of such widely different origins approach very near to each other in microscopic appearance.

MARBLES.

The marbles are composed of a mosaic of anhedral calcite grains of varying size, and contain small amounts of other minerals according to the nature of the impurities present, as, for example, the marble with small amounts of wollastonite present which has already been mentioned. Another marble, occurring north of the town of Elkhorn, shows in the hand specimen many slender black needles which under the microscope prove to be skeletal crystals of tremolite, the crystals being hollow and having grown through the marble without the power of excluding it from the interior.

From the previous petrographical studies it has become evident that even under the most intense metamorphism the carbonic acid is not expelled from the limestone except by the presence of silica and the other impurities which accompany it. This fact has been noted elsewhere by other observers, and disproves for the Elkhorn district any extensive migration of magmatic material into the sediments.

THE GOLD BELT OF THE BLUE MOUNTAINS OF OREGON

BY

WALDEMAR LINDGREN

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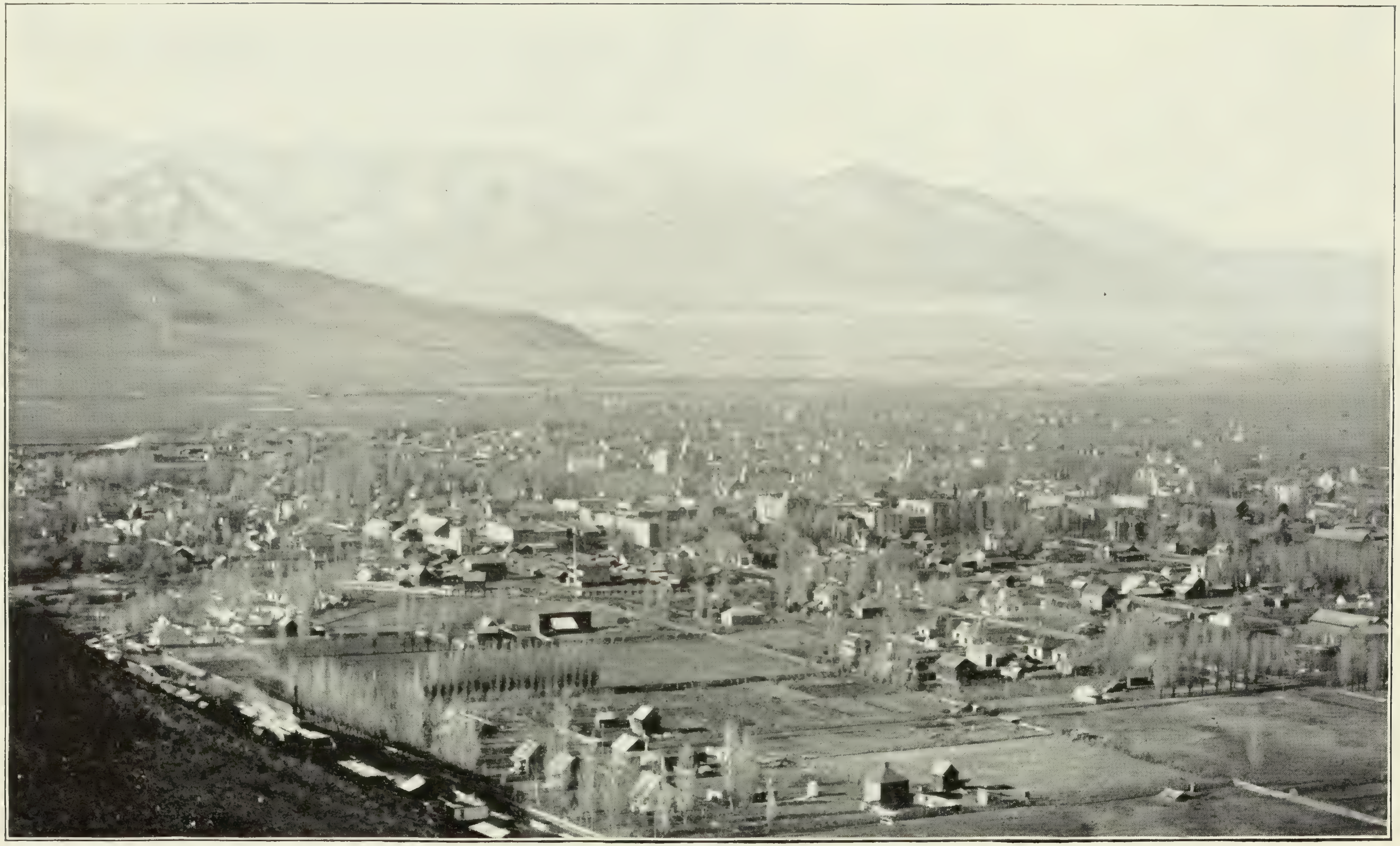

BAKER CITY.

THE GOLD BELT OF THE BLUE MOUNTAINS OF OREGON.

By WALDEMAR LINDGREN.

CHAPTER I.

INTRODUCTION.

GEOGRAPHIC POSITION, FIELD WORK, AND ACKNOWLEDGMENTS.

The State of Oregon contains several gold-bearing areas, widely scattered over different regions. Practically its whole coast is fringed by a belt of auriferous sands which sometimes are rich in fine gold. A second gold field is situated in the southern part of the State, chiefly in Jackson and Josephine counties, and may be considered as an extension of the gold belt of northern California. A third auriferous region is that of the Calapooya Mountains, extending northward toward the Santiam River and centering in the Bohemia mines.[1] Here the gold and silver appear in veins contained in Neocene andesites and basalts. A fourth mineral-bearing area is reported from the Puebla Mountains, in the extreme southeastern part of the State.

But the most important gold field of Oregon is that of the Blue Mountains. It is situated in the northeastern part of the State, and extends for a distance of about 130 miles westward from Snake River. Its production is at least three-fourths of the total output of the State. The present report deals exclusively with this region, which during the last few years has again assumed the prominent position among the gold-bearing areas of the United States which it held about forty years ago, when gold was first discovered there.

The present report is the result of an examination of the Blue Mountains made during a period extending from August to December, 1900, and undertaken by order of the Director of the United States Geological Survey. It will be conceded that four months is a short time in which to examine such an extensive territory and such a wealth of mineral deposits. The report therefore partakes of the character of preliminary or reconnaissance work, and should be judged accordingly. It was not possible to visit all the mines and prospects in the gold belt. The most prominent were naturally selected, but it should be emphasized that the failure to mention any particular deposit in this report is by no means a reflection on it or an indication that it lacks value.

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[1] The Bohemia mining region of western Oregon, by J. S. Diller: Twentieth Ann. Rept. U. S. Geol. Survey, Part III, 1900, pp. 7-36.

A large proportion of the data concerning mines and mining in this report has, of course, been obtained from the men who are in charge of the mining operations in the Blue Mountains, and to all of them my best thanks are due. With two conspicuous exceptions, permission to visit the mines was cheerfully extended and information readily given. Among the many to whom I am under obligations I would specially mention Messrs. E. Melzer, F. R. Mellis, J. Arthur, F. E. Cabell, H. S. McCallum, N. C. Haskell, and J. H. Pomeroy.

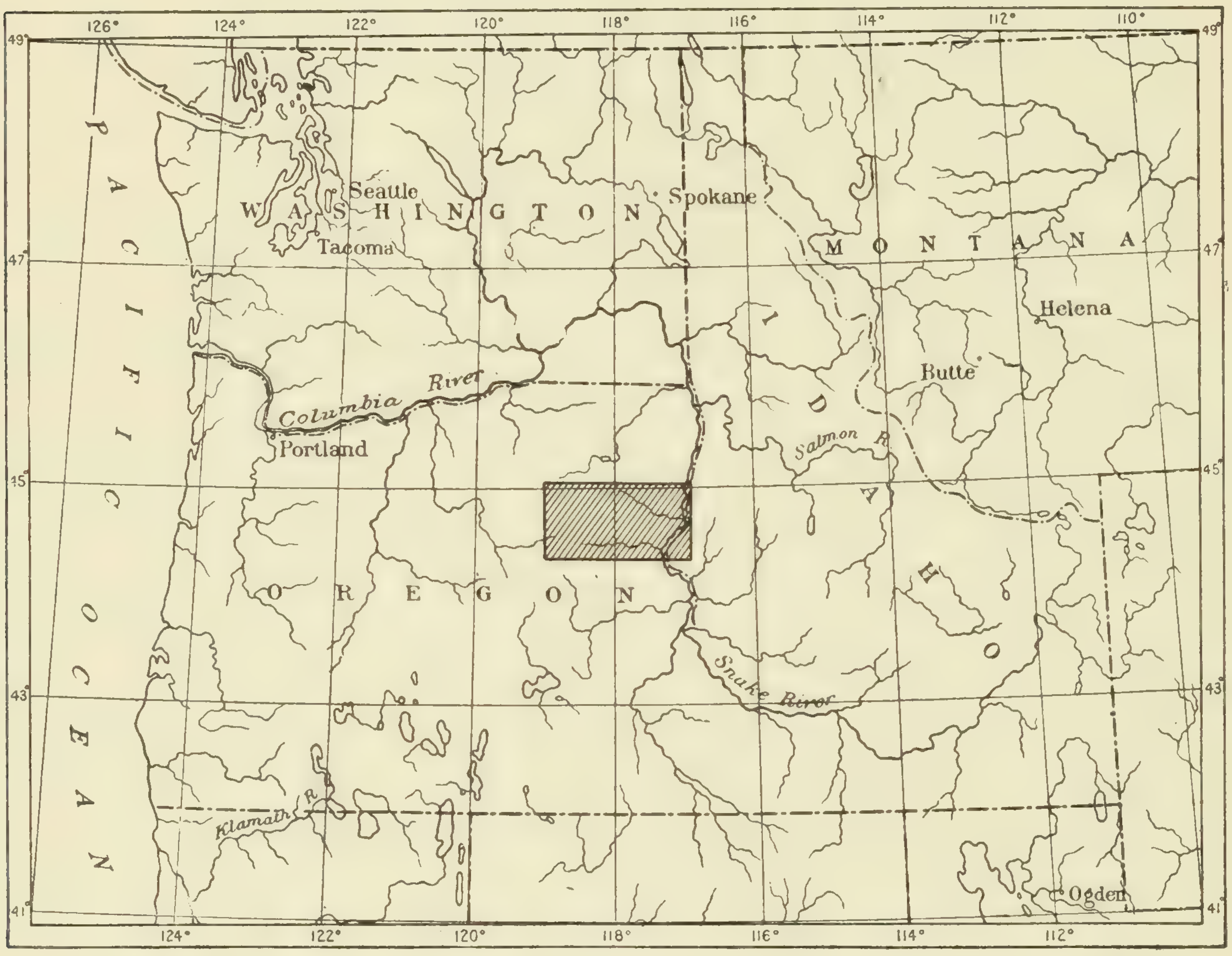
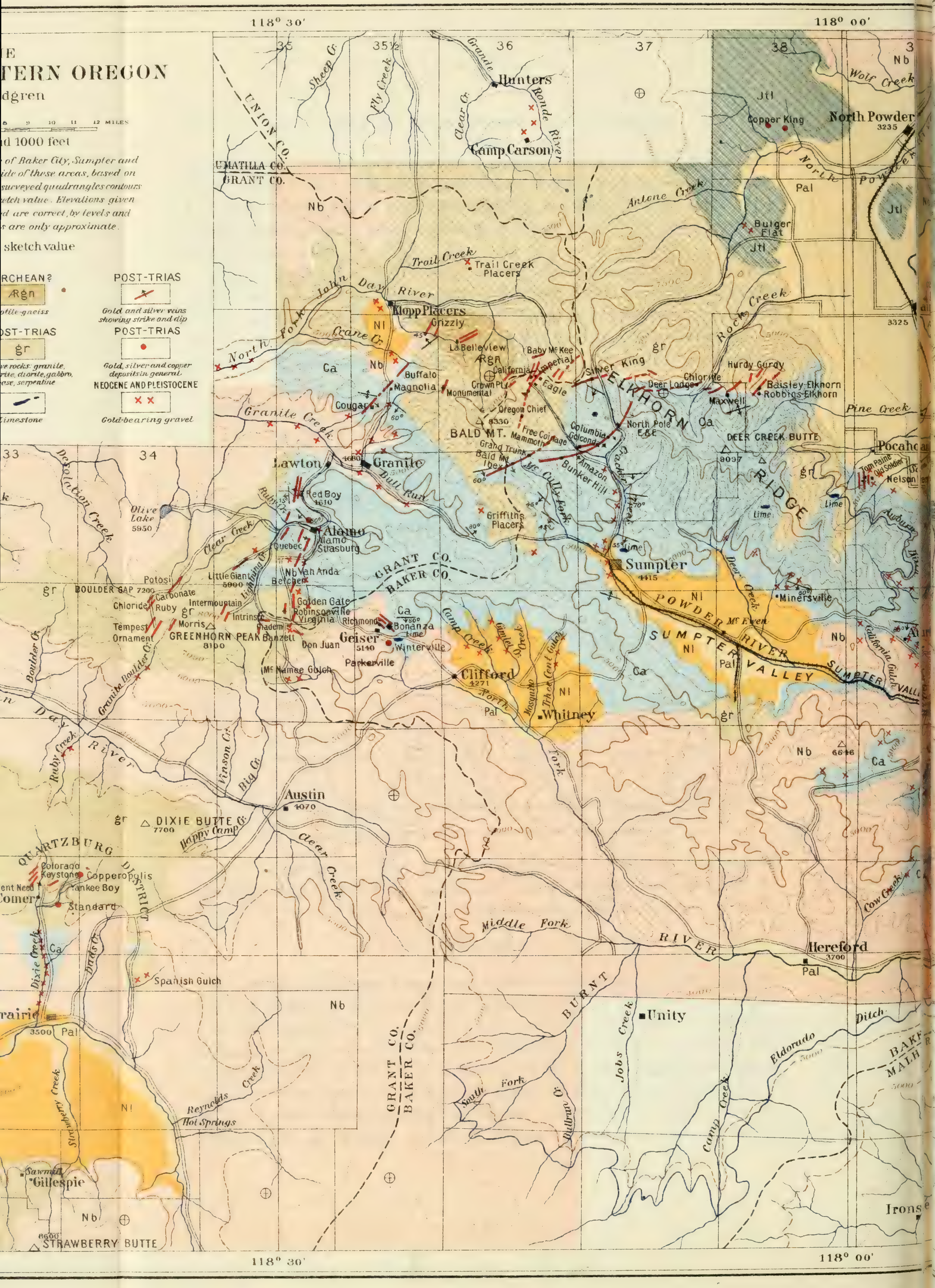
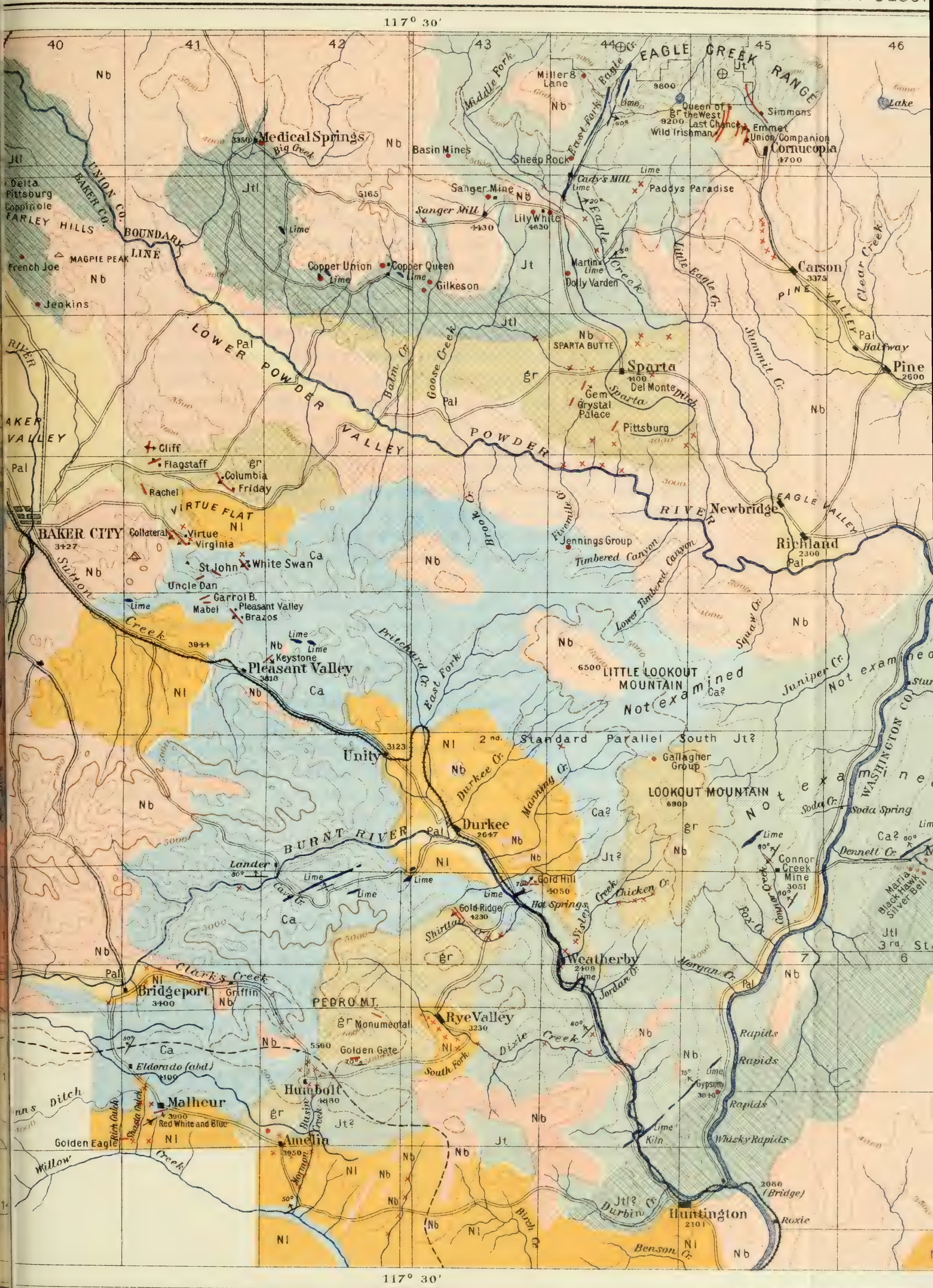


FIG. 79.—Index map of Northwestern States, showing location of special map.

THE MAP.

In order to present graphically the distribution of the mineral-bearing areas, the accompanying map (Pl. LXIV) has been prepared. The data contained in it require a few words of explanation. The map is based on the triangulations and the determination of latitude and longitude made by Mr. S. S. Gannett, of the United States Geological Survey. The Sumpter, Baker City, and Weiser (Idaho) atlas sheets of the United States Geological Survey, surveyed by Messrs. L. C. Fletcher, R. H. McKee, and E. T. Perkins, have been reduced to the


IE
TERN OREGON
dgren
8 9 10 11 12 MILES
d 1000 feet
of Baker City, Sumpter and
ide of these areas, based on
surveyed quadrangles contours
etch value. Elevations given
d are correct, by levels and
s are only approximate.
sketch value
RCHEAN?
Ægn
otite-gneiss
OST-TRIAS
gr
ve rocks: granite,
rite, diorite, gabbro,
ese, serpentine
Limestone
POST-TRIAS
Gold and silver veins showing strike and dip
POST-TRIAS
Gold, silver and copper deposits in general
NEOCENE AND PLEISTOCENE
Gold-bearing gravel
118° 30'
118° 00'
35
35½
36
37
38
33
34
UNION CO.
UMATILLA CO.
GRANT CO.
GRANT CO.
BAKER CO.
Hunters
Camp Carson
Sheep Cr.
Fly Creek
Grande Ronde River
Clear Cr.
Wolf Creek
Copper King
North Powder
3235
North Powder
Antone Creek
Bulger Flat
Jtl
Pal
Nb
Trail Creek
Trail Creek Placers
John Day River
North Fork
Klopp Placers
Grizzly
Crane Cr.
LaBelleview
Ægn
Baby McKee
Imperial
Silver King
California
Eagle
Buffalo
Magnolia
Monumental
Crown Pt.
Oregon Chief
Cougar
8330
BALD MT.
Mammoth
Free Coinage
Columbia
Golconda
Grand Trunk
Bald Mt.
Ibex
Amazon
Bunker Hill
ELKHORN
RIDGE
Deer Lodge
Chloride
Hurdy Gurdy
Baisley-Elkhorn
Robbins-Elkhorn
Maxwell
North Pole
E.&E.
DEER CREEK BUTTE
9097
Rock Creek
Pine Creek
Pocahontas
Tom Paine
Old Soldier
Nelson
Lime
Auburn
Granite Creek
Lawton
Granite
4680
Bull Run
Red Boy
Ruby Cr.
Alamo
Quebec
Strasburg
McCully Fork
Cracker Creek
Griffiths Placers
Sumpter
4415
Olive Lake
5950
Desolation Creek
Clear Creek
Little Giant
5900
Potosi
Van Anda
Belcher
Lightning Cr.
BOULDER GAP 7200
Carbonate
Chloride
Ruby
Intermountain
Intrinsic
Tempest
Morris
Ornament
GREENHORN PEAK
8100
Golden Gate
Robinsonville
Virginia
Diadem
Banzett
Richmond
Bonanza
Geiser
5140
Winterville
Don Juan
Parkerville
McNamee Gulch
Camp Creek
Ginger Cr.
Mosquito
Three Cent Gulch
Clifford
4271
Whitney
North Fork
Deer Creek
POWDER RIVER
SUMPTER VALLEY
McEwen
Minersville
California Gulch
6646
Boulder Cr.
Granite Boulder Cr.
John Day River
Ruby Creek
Vinson Cr.
Big Cr.
Austin
4070
DIXIE BUTTE
7700
Happy Camp
QUARTZBURG DISTRICT
Colorado
Keystone
Copperopolis
Present Need
Yankee Boy
Comer
Standard
Dixie Creek
Dads Cr.
Middle Fork
RIVER
BURNT
Cow Creek
Hereford
3700
Spanish Gulch
Prairie
3500
Unity
Jobs Creek
South Fork
Bullrun Cr.
Camp Creek
Eldorado
Ditch
BAKER
MALHEUR
Reynolds Creek
Hot Springs
Strawberry Creek
Sawmill
Gillespie
8600
STRAWBERRY BUTTE
Ironside
Nl
Ca
gr
Nb
Pal
5000
6000
7000


117° 30'
40
41
42
43
44
45
46
EAGLE CREEK RANGE
Medical Springs
3350
Big Creek
Basin Mines
Miller & Lane
9800
Queen of the West
8200
Last Chance
Wild Irishman
Simmons
Emmet
Union Companion
Cornucopia
4700
Sheep Rock
Cady's Mill
Paddys Paradise
Sanger Mine
Sanger Mill
4430
Lily White
4630
Martin
Dolly Varden
Carson
3375
PINE VALLEY
Halfway
Pine
2600
Clear Creek
Little Eagle Cr.
Summit Cr.
Eagle Creek
East Fork
Middle Fork
UNION CO.
BAKER CO.
BOUNDARY LINE
Delta
Pittsburg
Coppinole
FARLEY HILLS
MAGPIE PEAK
French Joe
Jenkins
Copper Union
Copper Queen
Gilkeson
LOWER POWDER VALLEY
POWDER RIVER
Balm Cr.
Goose Creek
SPARTA BUTTE
Sparta
4100
Del Monte
Sparta Ditch
Gem
Crystal Palace
Pittsburg
BAKER VALLEY
RIVER
Cliff
Flagstaff
Columbia
Friday
Rachel
VIRTUE FLAT
BAKER CITY
3427
Collateral
Virtue
Virginia
St John
White Swan
Uncle Dan
Carrol B.
Mabel
Pleasant Valley
Brazos
Keystone
Pleasant Valley
3616
Sutton Creek
3944
Brook Cr.
Fivemile Cr.
Jennings Group
Timbered Canyon
Lower Timbered Canyon
Newbridge
EAGLE VALLEY
Richland
2300
Squaw Cr.
Pritchard Cr.
East Fork
LITTLE LOOKOUT MOUNTAIN
6500
Not examined
Juniper Cr.
Not examined
Unity
3123
2nd Standard Parallel South
Gallagher Group
LOOKOUT MOUNTAIN
6800
Durkee Cr.
Manning Cr.
Durkee
2647
BURNT RIVER
Lander
Cave Cr.
Gold Hill
4050
Hot Springs
Gold Ridge
4230
Shirttail Cr.
Sisley Creek
Chicken Cr.
Soda Cr.
Soda Spring
WASHINGTON CO.
Connor Creek Mine
3051
Connor Creek
Fox Cr.
Dennett Cr.
Maria
Black Hawk
Silver Bell
3rd St
Weatherby
2409
Jordan Cr.
Morgan Cr.
Clarks Creek
Bridgeport
3400
Griffin
PEDRO MT.
Rye Valley
3230
Monumental
Golden Gate
South Fork
Dixie Creek
Eldorado (abd.)
4100
Malheur
3900
Red White and Blue
Humbolt
4080
Basin Creek
Amelia
3950
Golden Eagle
Rich Gulch
Shasta Gulch
Willow Creek
Ditch
Mormon Basin
Birch Cr.
Rapids
Rapids
Gypsum
3810
Rapids
Lime
Kiln
Whisky Rapids
2080 (Bridge)
Roxie
Durbin Cr.
Huntington
2101
Benson Cr.
Lake
Nb
Nl
Jtl
Jt
Pal
gr
Ca
Ca?
Jt?
Jtl?
Lime
117° 30'

scale of the map and used as a basis. The first two sheets include the region extending from latitude 44° 30′ to 45° and from longitude 117° 30′ to 118° 30′. For the country outside of these three quadrangles the base for townships and drainage has been the General Land Office map. The contours drawn at 500 feet vertical interval have been sketched by myself in the field. Excepting in the area of the three atlas sheets mentioned, they are to be regarded as approximate only, but they will serve to give a general idea of the character of the country. In the compilation of the data outside of the special quadrangles the mining map of eastern Oregon, issued by Mr. John Hagel, of Baker City, has been extensively used. Similar maps, issued by the Oregon Railroad and Navigation Company and by Mr. Arthur Philbrick, have also been found of use. As to the mineral veins indicated on the map, their position has been ascertained partly by independent observation, partly from data obtained from the surveyor-general's office, and partly from claim maps of the different regions issued by Mr. John Hagel.

Owing to the hasty nature of the field work, it is with considerable hesitation that it has been decided to indicate the geological areas on the map, but it is believed that the indication of the various rocks will so greatly help the understanding of the problems involved that, although imperfect, it should not be omitted. It must be expressly emphasized, however, that the outlines are only approximate in many cases.

PREVIOUS EXPLORATIONS.

From a geological standpoint, the gold belt of eastern Oregon has practically been an unknown region. The only data available to the student are those contained in Raymond's reports.[1] Though these reports deal more extensively with mining and the production of mines, there are, for instance in the report of 1870, some general notes on the geology of the region.[2] Notes regarding production are to be found in the various reports on the production of gold and silver by the Director of the Mint. The data contained in this report, therefore, to some extent fill a gap in our knowledge of the western United States.

HISTORY AND SETTLEMENTS.

While the gold fields in the southwestern part of Oregon were discovered about 1852, those of the Blue Mountains remained unknown until about ten years later. In the fall of 1861 a prospector named Griffin, with a party of men, discovered what is known as Griffin Gulch, a tributary of Powder River, a few miles southwest of Baker City. At that time the only settlement in the Blue Mountains was that of some cattle raisers in Grande Ronde Valley. Early in the spring of 1862 D. Littlefield and a party of four or five men were prospecting in the same neighborhood and discovered the rich placers of Auburn. In a very short time miners came pouring in from all directions, and the town of Auburn, laid out in June, 1862, grew rapidly, until in less than a year it contained 5,000 inhabitants. In those days the Blue Mountains were difficult of access, supplies having to be brought in from The Dalles, a distance of 300 miles. The mines of Auburn were found to be extremely rich, and from this center exploring parties penetrated the surrounding region in all directions. Prospectors from Auburn discovered the Boise Basin and the Owyhee mines in Idaho. The placers of Sumpter, Canyon, Mormon Basin, and Rye Valley were also discovered by men from the same camp, so that by 1864 practically all of the mining districts of the Blue Mountains were known. The yield per man was at least $8 per day, and any gravels containing less than this were not considered by the early prospectors.

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[1] Statistics of Mines and Mining in the States and Territories West of the Rocky Mountains, by R. W. Raymond, Washington, 1870, 1871, 1872, 1873, 1874, and 1875.

[2] Notes in regard to the mining industry may also be found in the report of J. Ross Browne on the mineral resources of the States and Territories west of the Rocky Mountains (Washington, 1868).

It was soon seen, however, that profitable mining was dependent upon water supply, and in the next few years much capital and labor were devoted to the construction of ditches. In 1863 the Auburn canal, taking its water from Pine Creek and other gulches in the Elkhorn Range, was completed. The Rye Valley ditch was constructed in 1864. The Sparta ditch, carrying the waters of Eagle Creek down to the dry hills of Sparta, a distance of 22 miles, was completed in 1873. About the same time a project was carried out supplying the Malheur diggings with water from the head of Burnt River. This canal, called the Eldorado ditch, was finished in 1873. Its total length is over 100 miles.

By means of these ditches much ground which formerly was inaccessible or too poor to work became available. About 1870 the richest placers were exhausted and a gradual decline in the production began, which may be said to have continued until the present time. From an output of several million dollars in 1870 the product of the placer mines has gradually diminished to something like $200,000 in 1899. During the last years the decline has been very gradual, and it is likely that a production of $200,000 may be kept up for many years to come, as low-grade gravels are beginning to be worked by modern processes of dredging.

While the placer mines declined, another industry, that of quartz mining, gradually developed. We find records of quartz mines being worked in Susanville and at Mormon Basin in 1865 and 1868. One of the first mills was built at Susanville in 1869 and the process used was pan amalgamation. The Virtue mine was discovered soon after 1862, and the Connor Creek mine in 1872, when the first prospecting in the vicinity of Cable Cove was begun and La Belleview and Monumental mines were worked. The ore was shipped on horseback for several hundred miles. Under such conditions the development of quartz mining was necessarily slow. Its active development dates from 1885, when the country was made accessible by the construction of the transcontinental railroad now traversing it. About 1886 valuable discoveries were made in the Eagle Creek Mountains near Cornucopia. From 1889 a rapid increase in the production was noticed. Quartz mines were worked in various parts of the country and some of them produced heavily. A number of mines in the Cracker Creek district were then, for the first time, considered worthy of exploitation and soon began to add to the annual production. This quiet development continued until 1899, when public attention was drawn to the extremely gratifying results obtained from the quartz mines in the Sumpter, Granite, and Bonanza districts. The West seemed suddenly to become aware that the long-neglected gold fields of the Blue Mountains had far greater value than was commonly attributed to them. In 1899 and 1900 a strong influx of prospectors and miners from all parts of the West took place, and under the stimulus of this new immigration and the introduction of modern methods of mining the country has rapidly developed. Prospectors have penetrated the whole region, searching for gold and silver veins. While this "boom" has probably induced over speculation, and in some cases an exaggerated notion of values, it has served to make the country better known and many valuable mines have been opened as a consequence of it.

The supply point for the largest part of the mining region is Baker City, a flourishing town in the Powder River Valley, having a population estimated at 7,000. The dormant camp of Sumpter was revived during the boom of 1899 and is now a prosperous mining town. Auburn, once flourishing, is now practically deserted. Canyon, in the John Day Valley, still remains a mining town of some importance. Other settlements of note are Union, located 30 miles north of Baker City, from which the camps of Eagle Creek Range largely receive their supplies, and Huntington, 40 miles southeast of Baker City, which is the supply point for the mining camps of Rye Valley, Malheur, Connor Creek, and Mineral. According to the last published census (1890) the population of the three counties, Baker, Union, and Grant, numbered 23,900.

Although the larger part of the area consists either of mountains and forests or dry foothills, there are several agricultural districts of great value. South of the Eagle Creek Mountains are the beautiful valleys of Pine and Eagle, which have a mild climate. Along the lower Powder River a belt of fertile bottom lands extends for a distance of 20 miles. The largest agricultural area is that of Baker Valley, 18 miles long by 10 miles wide. This has a somewhat higher elevation and its climate is a little colder than that of the valleys previously mentioned. West of Baker City extends a vast area of mountains and canyons, the only agricultural areas of importance being Sumpter and Clifford valleys, which, however, are at elevations over 4,000 feet, and are chiefly used for pastures and hay lands. Very little agricultural land is found on the North and Middle forks of John Day River. On the South Fork of the same river, however, extends the fertile John Day Valley, having a length east to west of about 20 miles and a width up to 10 miles. The John Day Valley is justly celebrated for its excellent fruit and beautiful alfalfa fields. It has an elevation of about 3,200 feet, and is one of the oldest agricultural settlements in eastern Oregon.

Practically all of the agricultural lands of the Blue Mountain must be irrigated if heavy and profitable yield is desired. On certain rich bottom lands it is possible to raise a crop of hay or cereals without irrigation, but this is exceptional. In the Baker Valley are large areas which could be cultivated if water were available, and a project is now on foot to obtain it by storing the flood water of Powder River during the winter and gradually distributing it through the summer.

CLIMATE AND VEGETATION.

Owing to the great diversity in elevation and situation, the climate in the Blue Mountains varies considerably from place to place. Along the Snake River and the contiguous valleys a dry, warm climate prevails, with little rain and snow. At Baker City the average precipitation for a period of ten years was 13 inches, varying from 4.17 to 18.23 inches per annum. The temperature during the last ten years shows variations from +110° in July to a minimum of −17° in the winter. In the mountain region west of Baker City the rain and snow fall increases rapidly with the elevation. Showers during the summer are of frequent occurrence, and the winter snows are from 5 to 15 feet deep.

The vegetation is, of course, largely dependent upon the meteorological conditions. Arid foothills without forest growth, but with a sometimes luxuriant vegetation of grass and sagebrush, extend from Baker City to Snake River. East of Baker City the mountain region is covered with a heavy growth of timber, except the highest, once-glaciated areas, which have been swept bare of soil by the ice streams. The northwestern part of the area described has the greater precipitation and the more abundant vegetation. The southeastern part, sloping toward the great interior valley of Snake River, is dry and destitute of forest growth. Bare foothills extend from Huntington westward over the lower part of Willow Creek and Burnt River. On the whole, it may be said that an elevation of 4,000 feet marks the timber line. Below this elevation there are only scattered groups of trees.

Except for willows and alders along the water courses, the forests consist entirely of coniferous trees. The most important of these is the yellow pine, which attains its best development at an elevation of from 4,000 to 5,000 feet. Above 5,000 feet the timber is usually of poor quality, consisting largely of black pine and tamarack. The best timber is found on the headwaters of Powder River, Burnt River, and the Middle Fork of John Day, while on the North Fork of John Day the growth appears to be of inferior character.

MINING AND METALLURGY.

In eastern Oregon mining is usually carried on under favorable circumstances. Wood, timber, and water are ordinarily in good supply. The principal drawback is the distance of some camps from railroad lines, and in the highest mining districts the severe climate, as, for instance, at Cable Cove, on the Greenhorn Ridge, and at Cornucopia. No special comment is required in regard to methods of mining. In many cases lack of technical skill has materially increased the difficulties. Men of various professions have been sent out to take charge of mines, instead of experienced mining engineers. At some prospects, and even at some mines, manifestly unsafe shafts and machinery were found. Still, these matters have greatly improved and many of the mines are now models of their kind. The cost of mining may be taken to vary from $1 to $4 per ton in the large mines having considerable bodies of ore 2 to 6 feet wide. According to Mr. J. Arthur, the E. and E. mined their vein from a shaft 200 feet deep, at a cost of $1.85 per ton. The cost of mining at the Columbia mine, hoisting from a shaft 500 feet deep, is supposed to be $3 per ton.

The simplest and most satisfactory ores are those of mainly free milling character, like the Red Boy, Bonanza, and Belle of Baker veins. The cost of milling with plate amalgamation and concentration is rarely over $1 per ton. At the E. and E. mine, according to Mr. Arthur, milling costs $1.05 per ton, giving a total for mining and milling of $2.90 per ton. At the Bonanza the mining and milling are believed to cost from $2.50 to $3 per ton. At the Red Boy the total expenses are said to be a little heavier, possibly reaching $4 per ton. Sometimes it is necessary to subject the tailings to the cyanide process, and this will increase the total cost by at least $1 per ton. When the ore is roasted and subjected to direct cyaniding, as at the North Pole mine, the expense naturally becomes higher. In the mines which produce large amounts of concentrates or sulphide ores, which must be shipped to smelting works, the cost of treatment is, of course, greatly increased, freight and smelting charges amounting to at least $5 each, or a total of $10, besides heavy wagon freight if the mine is situated far from railroad. Anything containing less than $25 per ton is usually not considered shipping ore. Frequently the total charges reach $30 per ton. Last year an attempt was made to run a small smelting plant at Sumpter, but even with the most careful management there are great drawbacks to such an enterprise; the main ones are expensive coke and the absence of large quantities of suitable copper and lead ores. Smelting of cupriferous pyrite by the pyritic process was for some years successfully carried on at the camp of Mineral, on Snake River.

Regarding the percentage of extraction, exact data are difficult to obtain. It is not probable that any mill at present works closer than 80 to 85 per cent, and many of them fall considerably short of this figure.

The ores from veins in argillite, which in their normal, fresh state consist of hard quartz with finely disseminated pyrite and arsenopyrite, have from the start proved a difficult problem for the metallurgist, and useless plants, erected without due deliberation and preliminary tests, have absorbed a heavy expenditure, which could have been avoided by more skill and care.

It seems that the values are chiefly contained in the fine-grained sulphurets inclosed in the quartz; but besides this there are in the different shoots great variations in the relative percentage of gold and silver, as well as in the state of the gold. The surface ores—that is, down to a depth of 100 to 200 feet below the surface—are partly oxidized. While this frees a part of the gold, another part is still held by the sulphides. The surface ores can therefore usually not be treated by amalgamation and concentration except when, as in the Red Boy and Bonanza, the proportion of free gold is great. The cyanide process has been used for these ores. Even then it is necessary to roast the ore carefully before the cyanide solution is applied, a fact which of course considerably increases the cost. When, as in the case of the base ore of the E. and E., the concentration process was used for surface ore, the extraction only averaged from 50 to 60 per cent, the percentage saved increasing at the rate of 10 per cent for every 50 feet of depth gained.

In cyaniding the similar North Pole ores, on the other hand, the extraction was found to be 85 per cent on ore averaging 0.753 ounce of gold and 0.967 ounce of silver per ton.

In using the plate amalgamation and concentration method on the deep ores the percentage of gold saved on the plates varies from a few per cent up to 60 and above, the highest savings being found in the Bonanza and the Red Boy ores. Successful concentration of these ores depends largely upon the manner in which the crushing is effected. Mr. J. Arthur informs me of the following experiment in this direction: A mill sample was taken for thirty days from the E. and E. ore, when this mine was running, crushing through a 50-mesh screen. This sample assayed $11.50 per ton, and the mill extraction for this month was 51 per cent. The fine slimes from the mill would sometimes run somewhat higher than the ore. Concentrated in gold pan in the laboratory, only 48 per cent was recovered. Ten pounds of this sample were then crushed to one-fourth inch size, and it was found that 28 per cent of the value could be saved by jigging. The tailings from the jig were then crushed through 10-mesh screen, and 26 per cent again saved by jigging. The tailings from the jig were recrushed through 40-mesh screen and run over vanners. The three crushings resulted in a total saving of 83½ per cent. This would seem to indicate the method to be pursued for disseminated sulphide ores, without free gold. At present the stamp mill usually crushes directly to 50-mesh screens and the pulp is run over vanners. Lately, at the Columbia mine, the tailings have been saved, and it is reported that it has been found practicable to cyanide the tailings, without roasting, with 76 per cent extraction, by a five-day percolation, the cost of the cyaniding being as high as $1.50 per ton.

PRODUCTION OF GOLD AND SILVER IN OREGON.

As by far the largest proportion of the production of the precious metals comes from the Blue Mountains, it may be pertinent to give the figures relating to the production of the State as a whole. During the earlier years statistics were very incomplete. Gold and silver were not separated, and, indeed, for a number of years the production of Washington was included in that of Oregon. The former did not, however, amount to very much.

The product for the four years from 1862 to 1865, inclusive, is not known, even as an estimate. It would not be surprising if it reached $50,000,000, as the years closely following the discovery marked the high point of production. The product in 1865 is doubtfully estimated at $20,000,000 (J. Ross Browne).

Production of gold and silver in Oregon and Washington from 1866 to 1875, inclusive.

[Compiled from the official reports on the production of the precious metals by J. Ross Browne and W. R. Raymond.]

Year.	Gold and silver.
1866	*a* $8,000,000
1867	3,000,000
1868	4,000,000
1869	3,000,000
1870	3,000,000
1871	2,500,000
1872	2,000,000
1873	*b* 1,376,400
1874	*c* 609,070
1875	*c* 1,246,978
Total	28,732,448

a Estimated by some as high as $20,000,000.

b Estimate of total by Wells, Fargo Express Company; Oregon only.

c Oregon only.

There are no official statistics for 1876, but the production may be roughly estimated at $1,100,000. From 1877 to the present time somewhat more accurate statistics are available, which are given below. It should be stated, however, that the silver production does not appear to be reliable, as in many returns from placer mines the relatively small amount of silver is apparently overlooked. Moreover, as the silver value given is the coining value, or $1.29 per ounce, the returns for the years later than 1884 are misleading, the price of silver having declined to about 60 cents per ounce.

Production of gold and silver in Oregon from 1877 to the present time.

[From the reports of the Director of the Mint on the production of the precious metals.]

Year.	Gold.	Silver (coinage value).	Total.
1877	$1,000,000	$100,000	$1,100,000
1878	1,000,000	100,000	1,100,000
1879	1,150,000	20,000	1,170,000
1880	1,090,000	15,000	1,105,000
1881	1,100,000	50,000	1,150,000
1882	830,000	35,000	865,000
1883	660,000	3,000	663,000
1884	660,000	20,000	680,000
1885	800,000	10,000	810,000
1886	990,000	5,000	995,000
1887	900,000	10,000	910,000
1888	825,000	15,000	840,000
1889	1,200,000	38,787	1,238,787
1890	1,087,000	129,199	[a] 1,216,199
1891	1,994,622	296,280	2,290,902
1892	1,491,781	64,080	1,555,861
1893	1,690,951	13,557	1,704,508
1894	2,113,356	10,315	2,123,671
1895	1,837,682	15,192	1,852,874
1896	1,290,964	71,811	1,362,775
1897	1,354,593	109,643	1,464,236
1898	1,216,669	165,916	1,382,585
1899	1,467,379	187,932	1,655,311
Total	27,749,997	1,685,712	29,435,709

[a] Census reports: Gold, $964,000; silver, $23,383; total, $987,383.

The data show a gradual decline in production from the heyday of placer mining in 1862–1866 to less than a million dollars ($663,000) in 1883. From this time quartz mining on a larger scale begins to show its influence, and during the last decade of the century the production rises to between one and two millions, exceeding the latter amount during two years. The production for the last few years averages $1,400,000, and it is believed the product of 1900 will show a considerable increase over that of 1899.

The total production of gold in Oregon from 1866 to 1899, inclusive, is approximately $59,000,000. Adding to this the production from date of discovery, 1861 to 1865 inclusive, very roughly estimated at $50,000,000, we obtain the whole production of gold and silver in Oregon as $109,000,000. Silver forms but a small fraction of this amount.

PRODUCTION OF GOLD AND SILVER IN THE BLUE MOUNTAINS.

The production of the three counties of the Blue Mountains is very imperfectly known previous to 1880. From that year (except in 1896) detailed statistics have been given in the Mint reports, and in the reports from 1889–1892 individual reports from the separate mines as well. It is much to be regretted that this could not be kept up, the chief difficulty being the objection of the average mine owner to having his production published. In looking over the following compiled tables it becomes apparent that many inaccuracies and discrepancies clearly exist, so that the figures are at best only approximate. Still they serve to give an idea of the relative importance of the counties and the fluctuations in the production. A comparison with the total production of Oregon shows that the largest part of the output is to be credited to the Blue Mountains.

Baker County, containing the most important quartz mines of the central belt, leads in production. The totals, though fluctuating greatly, approximate $1,000,000 per year, and the production is on the whole increasing. Grant County, containing chiefly placer mines, shows a smaller production, between $100,000 and $300,000. The yield was, on the whole, decreasing up to 1898, when a notable increase appeared.

Union County was of less importance as a producer up to 1889, when, owing to the discovery of rich quartz veins at Sanger and Cornucopia, the yield suddenly increased, and in one year (1894) exceeded $1,000,000.

The returns from Malheur County, in which the mining districts of Malheur, Amelia, and Mormon Basin are situated, have, until the last few years, been included in the amounts reported from Baker County.

The grand total of $18,000,000 shows the total production of the mining districts of the Blue Mountains from 1880 to 1899 inclusive.

The Mint reports for the years 1897 and 1898 give also for the State of Oregon the relative amounts of gold and silver contained in placer bullion, mill bullion, and smelting ore, thus furnishing an opportunity to compare the relative importance of placers, free milling, gold-quartz mines, and mines containing base ore. Some very rich ore from gold-quartz mines may, however, be included in the latter amount. The diminishing importance of the placers is clearly perceived, it being from one-fourth to one-fifth of the total amount.

Source of gold and silver in Oregon for 1897, 1898, and 1899.

[From the reports of the Director of the Mint.]

	Gold.		Silver.		Total.
	Quantity.	Value.	Quantity.	Value.	
1897.	*Fine ounces.*		*Fine ounces.*		
Placer bullion	17,170	$354,931	3,908	$5,053	$359,984
Mill bullion	29,587	611,616	41,302	53,400	665,016
Smelting ores and concentrates	18,772	388,046	39,592	51,189	439,236
1898.					
Placer bullion	14,289	295,381	3,254	4,207	299,588
Mill bullion	24,770	512,040	24,419	31,572	543,613
Smelting ores and concentrates	19,797	409,248	100,653	130,137	539,385
1899.					
Placer bullion	13,887	287,070	2,722	3,519	290,589
Mill bullion	30,954	639,876	13,904	17,977	657,853
Smelting ores and concentrates	26,143	540,432	128,728	166,436	706,868

Production of gold and silver in Baker, Grant, and Union counties, Oreg., from 1880 to 1899.

[Compiled from the reports of the Director of the Mint.]

Year.	Baker.			Grant.			Union.			Total.
	Gold.	Silver.	Total.	Gold.	Silver.	Total.	Gold.	Silver.	Total.	
1880	$226,647	$400	$227,047	$85,400	$543	$85,943	$60,347	....	$60,347	$373,337
1881	250,000	10,000	260,000	280,000	20,000	300,000	40,000	....	40,000	600,000
1882	190,000	5,000	195,000	240,000	25,000	265,000	60,000	$800	60,800	520,800
1883	160,000	2,500	162,500	200,000	15,000	215,000	45,000	300	45,300	422,800
1884	160,000	2,500	162,500	200,000	15,000	215,000	45,000	300	45,300	422,800
1885	348,044	....	348,044	194,600	....	194,600	7,322	....	7,322	549,966
1886	396,115	9,005	405,120	198,580	....	198,580	20,650	....	20,650	624,350
1887	173,558	5,153	178,711	163,896	11,797	175,693	15,000	....	15,000	369,404
1888	190,000	5,000	195,000	140,000	10,000	150,000	15,000	....	15,000	360,000
1889	463,604	7,500	471,104	73,989	9,550	83,539	574,989	1,028	576,017	1,130,660
1890	335,000	127,540	462,540	90,000	129	90,129	400,000	....	400,000	952,669
1891	873,058	217,833	1,090,891	124,487	4,297	128,784	625,956	3,500	629,456	1,849,131
1892	367,587	3,257	370,844	53,780	40	53,820	753,715	1,900	755,615	1,180,279
1893	728,947	10,454	739,401	198,650	....	198,650	420,237	3,046	423,283	1,361,334
1894	447,996	2,251	450,247	129,853	....	129,853	1,059,070	8,100	1,067,170	1,647,270
1895	942,483	7,963	950,446	101,853	....	101,853	144,800	3,000	147,800	1,200,099
1896[1]	800,000	20,000	820,000	100,000	....	100,000	300,000	....	300,000	1,220,000
1897	796,741	50,088	846,829	86,969	4,880	91,841	211,699	36,071	247,770	1,186,440
1898	525,945	42,690	568,635	143,463	32,769	176,232	292,324	67,816	360,140	1,105,007
1899	582,348	55,418	637,766	217,054	86,626	303,680	114,212	19,466	133,678	1,075,124
Total	8,958,073	564,552	9,542,625	3,022,564	235,631	3,258,197	5,205,331	145,327	5,350,648	18,151,470

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[1] No product by counties given in mint reports. Figures for this year are only rough estimates.

CHAPTER II.

GEOLOGY.

TOPOGRAPHY.

Relief.—The Blue Mountains are situated in the northeastern corner of the State of Oregon. They form an irregular complex of mountain groups which as a whole may appropriately be regarded as a projecting spur from the great central mountain mass of Idaho. On the east, near the Idaho boundary line, which follows Snake River, high plateaus adjoin the mountains and continue into Idaho. The northwesterly limit is well marked by the broad ridge which swells to elevations of 4,000 to 5,000 feet from the lower plateau of the Columbia River and which continues from the southeastern corner of Washington in a southwesterly direction for at least 150 miles toward the John Day River. The westerly limit may be extended to the Deschutes trough, which separates the Blue Mountains from the Cascades, and the southerly boundary is formed by the deserts of Malheur River and Harney Lake. This area includes a great diversity of lesser ranges in confusing complexity, due partly to displacement, partly to extremely heavy lava flows covering the old and probably structurally more simple ranges. A very irregular drainage, caused by the same lava flows, has cut deep valleys into the heterogeneous mass of mountains.

The northeastern part consists of a lava plateau from 4,000 to 5,000 feet high, above which rise the Eagle Creek Mountains, a circular group with a diameter of about 30 miles and elevations exceeding 9,000 feet. Within this plateau lie fertile valleys, at least one of which is a depressed area bounded by fault lines. About 30 miles west of the Eagle Creek Mountains is the Elkhorn Range. This is composed of older rocks, is continuous in a northwesterly direction for about 40 miles, and reaches an elevation of a little over 9,000 feet. Its western slope is not so sharply defined. A spur extends to Bald Mountain (elevation 8,330 feet), and lower ridges connect this high region of old rocks with the Greenhorn Ridge, which, with maximum elevation of 8,100 feet, continues for 30 miles in a general northwesterly direction. The Elkhorn and Greenhorn mountains form the largest area of old, pre-Neocene rocks in the Blue Mountains, which is surrounded practically on all sides by lava masses rising to irregular plateaus with elevations of 5,000 to 6,000 feet. West of the Greenhorn Mountains another pre-Neocene ridge, also surrounded by plateau-like lava masses, extends northwesterly from Dixie Butte (elevation 7,700 feet) toward Long Creek. Lastly, south of Dixie Butte lies the deep John Day Valley, and south of this rises, with an abrupt slope suggestive of a fault line, the imposing Strawberry Range, culminating in Strawberry Peak (elevation 8,600 feet). This range has a marked east-west trend, but it is not of uniform geological build, its eastern part being heavily covered with lava flows, while its western end is composed of pre-Neocene rocks.

To such a degree is the older pre-Neocene structure veiled by the lavas that it is difficult to obtain an idea of its probable configuration. It was by no means a unit, for it was separated into several masses by deep depressions and valleys of erosion; but its general trend was surely southwesterly, although folding movements of different age, faults, and extremely active erosion had greatly diversified its features.

Drainage.—With the exception of the few streams which find their way down to the plains of Harney Lake, the whole region drains either into the Snake or the Columbia River. Snake River pursues its course along the eastern border through the lava plateau, in a canyon which for about 50 miles north of Huntington varies from 2,000 to 3,000 feet in depth. In the high basaltic plateau just west of the Seven Devils this canyon is eroded to a depth of 5,000 feet or even more.[1] Near the mouth of the Grande Ronde the bottom is 3,000 feet below the basalt plateau.[2]

The northeastern plateau and the northern side of the Eagle Creek Mountains are drained by the Grande Ronde and Imnaha rivers, both flowing in sharply cut canyons. The former also cuts far back into the region of the northern Elkhorn Range and heads in the great granodiorite area north of Cable Cove, near Sumpter. The southeastern part of the Blue Mountains is drained by Powder and Burnt rivers. Powder River has a very remarkable course. Heading west of the Elkhorn Range, with a southeasterly direction, it soon turns sharply, in a deep canyon, and takes a northerly direction, which it maintains through Baker Valley. At the northern end of this valley is another, smaller canyon, and a still sharper turn to a southeasterly course, which it keeps until the junction with the Snake. Burnt River also heads in the central region near Sumpter, and then traverses a series of canyons and open valleys until, near Huntington, it joins Snake River.

The whole of the western drainage is through the three forks of John Day River. The North Fork heads near Cable Cove, a few miles north of Sumpter, and flows from there westward through deeply cut canyons. The Middle Fork heads near Austins, opposite Burnt River, and traverses the mountains in a deep but rather broad canyon or valley with a west-northwesterly direction. The South Fork of John Day River also has its source immediately west of the head of Burnt River and continues for 40 miles due eastward, flowing in the broad, open John Day Valley, bounded on the north by sloping basalt flows, and on the south by the abrupt buttresses of the Strawberry Range.

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[1] W. Lindgren: Twentieth Ann. Rept. U. S. Geol. Survey, Part III, 1900, p. 88.

[2] I. C. Russell: Water-Supply and Irrigation Papers U. S. Geol. Survey, No. 4, p. 25.

GENERAL GEOLOGICAL FEATURES.

The part of the Blue Mountains represented on the accompanying map consists of several cores of older rocks partly surrounded by floods of Neocene lavas, rhyolites, andesites, and basalts. If the map were extended somewhat farther north it would be seen that the same lavas entirely surround the northern part of the Elkhorn Range as well as the Eagle Creek Mountains. These cores of older rocks form a salient from the great mass of mountains filling central Idaho. The vast granite area which occupies so much space in central Idaho does not extend into Oregon, but ends some miles east of Snake River, near Huntington, against sedimentary rocks and old lavas which are believed to be of Triassic age. West of these beds, which have a general northeasterly strike, appears a series of argillites, strongly developed about Durkee and the Virtue district and equally strongly represented in the Elkhorn Range. These argillites, which have a general east-west strike, would appear, as far as the present incomplete examinations have been carried, to form a large syncline. In the Elkhorn Range the dips are prevailingly to the south, while in the southeastern part of the area northerly dips predominate. The whole series is moderately compressed, and if the structure were examined in detail many minor folds would probably be found. The rocks consist chiefly of argillites, often very siliceous. Coarse sediments are generally absent. Smaller masses of slates of probably the same age are found in the extreme western part of the area. The age of this series of argillites is believed to be Paleozoic and probably Carboniferous.

In the Eagle Creek Range, surrounded on all sides by high lava plateaus, another series of rocks appears which presents much similarity to the strata near Huntington mentioned above. It consists of shales and limestones with large masses of intercalated lavas. The beds lie nearly flat in the foothills, but are tilted, folded, and strongly metamorphosed in the central part of the mountains. Their age is Triassic, as shown by fossils found in several localities. The same Triassic rocks appear in the northeastern corner of the area exposed below the Neocene lavas of the Snake River Canyon.

In many places all of these sediments, the Carboniferous as well as the Triassic, are disrupted and contain larger or smaller intrusive masses of granite, granodiorite, diorite, gabbro, and serpentine. The granodiorite is most extensively developed in the northern Elkhorn

Range. Diorites, diabases, and serpentines prevail in the eastern part of the mapped area.

Baker Valley, in the center of the district, is the largest Pleistocene area. It is bordered on the east by low hills, while toward the west the imposing Elkhorn Range rises to elevations of 9,000 feet. At its base is a fault scarp, excellently exposed at the mouth of Salmon Creek in the Nelson placer mines, which indicates that the valley is largely an area of subsidence.

In its general aspect the region described is of the geological type so frequently found on the Pacific slope, consisting of closely folded Paleozoic and early Mesozoic strata, shattered by large masses of intrusive granular rocks and covered by Neocene lava flows.

THE ROCKS.

ARCHEAN.

The only area of gneiss in the region described occurs northwest of Bald Mountain, about La Belleview mine. The rock is a coarse-grained biotite-gneiss with prominent schistosity and sometimes a little contorted. The reddish-brown biotite forms large anhedral, often ragged foils. A few plates of muscovite are associated with it. Quartz in elongated grains is very abundant. There is only a very small amount of plagioclase and orthoclase. The composition indicates that the rock is of sedimentary origin, but it is far more altered than the ordinary contact-metamorphic slates. Below La Belleview mine the strike is N. 40° E. and the dip 45° W. The rock is usually sharply separated from the granite.

PALEOZOIC SEDIMENTS.

Rocks referred to the Paleozoic system occupy a large area in the lower Burnt River region, about Pleasant Valley, in the southern Elkhorn Range, and on the headwaters of Burnt River and Granite Creek. Smaller isolated areas of clay slate, inclosed in diorites, diabases, and serpentines, also occur near Susanville, in the Quartzburg district, and near Canyon. There is no clew to the age of these, but they are believed to belong to the same Paleozoic series. The prevailing rocks through the whole of this large sedimentary area are dark and very fine grained, ranging from cherts to siliceous argillites and ordinary clay slates. A large proportion of the sediments show no distinct stratification in ordinary outcrops, but in thin sections the carbonaceous streaks which indicate the planes of deposition are readily recognized. In many places, however, the rocks are normal clay slates of fairly fissile character.

In contrast to the heavy limestones of the Trias, this series contains only isolated lenses, ordinarily of no great length. The only large and persistent belt of limestones known in it is found west of Durkee, as shown on the map.

The cherts are gray to dark gray, and usually consist of extremely fine- and even-grained quartz aggregates. The siliceous argillites are similar, but contain more or less finely divided organic matter, shreds of sericite, and finely divided kaolin. The clay slates are extremely fine-grained rocks with streaks of finely distributed carbon, inclosing lenticular spaces of clearer substance, consisting of microcrystalline to cryptocrystalline aggregates of quartz with kaolin, sericite, chlorite, and calcite, and occasional prisms of tourmaline, rutile, and zoisite. In places the slates are calcareous and contain rounded or lenticular masses of fine-grained calcite. Pyrite and pyrrhotite are generally absent, except in the immediate vicinity of mineral veins. Larger clastic grains are not abundant. Near intrusive granitic rocks the argillites become brownish and somewhat crystalline through a conversion into allotriomorphic aggregates of biotite, quartz, and feldspar. A little magnetite and actinolite are also often present. Such rocks are found all along the main contacts, as, for instance, near the Baisley-Elkhorn vein; they usually extend only a few hundred feet from the contact. In the Present Need tunnel, in the Quartzburg district, a narrow streak of a peculiar dark-gray, almost flinty rock occurs, spotted by irregular black blotches. This consists of an interlocking quartz aggregate filled with sericite and containing bunches and spherulitic aggregates of tourmaline, accompanied by a little calcite. It is inclosed in diabase, and is probably a contact-metamorphic, tuffaceous clay slate.

The strata throughout the region have a well-marked east-west strike. The dip is prevailingly southward and ranges from 40° to 70°. Though the structure has not been definitely worked out, owing to the frequent difficulty of ascertaining strike and dip, it is probably a series of compressed folds. Schistosity is rarely observed, though at a few places in the Elkhorn Range and near Sumpter joint planes and incipient north-south schistosity transverse to the strike may be noted. The strike of the strata is a little north of west near Sumpter and Auburn, while south of Powder River it is from 10° to 20° south of west.

The only place where fossils were found is near the Bonanza mine, at Winterville, where round crinoid stems occur in a small mass of crystalline limestone. The other limestone lenses in the series, though carefully examined, yielded no fossils. Round crinoid stems are most common in Paleozoic rocks; taken in consideration with the fact that the series as a whole has a distinctly older appearance than the Triassic of Eagle Creek, from which it is also petrographically very different, we may with some confidence refer it to the Paleozoic and possibly to the Carboniferous. The series is similar to the Delhi division of the Calaveras formation in the Sierra Nevada,[1] which is believed to belong to the Carboniferous.

Well-defined Carboniferous fossils have been found by Professor Condon in the Crooked River drainage, in the extreme western part of the Blue Mountains.

PALEOZOIC LAVAS.

Compared to the Trias of Eagle Creek, the Paleozoic section is poor in intercalated lavas of the same age as the sedimentary beds. Greatly altered greenstones, of massive and roughly schistose structure, occur in it at Pleasant Valley, and at Unity, which is a railroad station south of that place; also on the road to Clifford from Sumpter, on McCully Fork, a few miles from Sumpter, and in Quartz Gulch, on Olive Creek. These rocks are so much altered that the original character can hardly be ascertained. They are chiefly tuffs, containing much chlorite, epidote, and calcite.

HUNTINGTON SERIES.

These sedimentary beds are exposed near the mouth of Burnt River and along Snake River below that place, at least as far as Mineral, and are described in detail on pp. 752–762. This series consists of limestones, calcareous shales, clay slates, and volcanic tuffs, of red and green color, resting, with flat dips of from 14° to 60°, on a basement of old volcanic rocks. The latter are well exposed in Burnt River Canyon near its mouth, and in the Snake River Canyon below Huntington. The prevailing rocks are greenish or grayish, massive, and fragmentary igneous rocks, showing no bedding nor schistosity. They seem to be largely old rhyolites and accompanying tuffs. The clay slates and limestones at Connor Creek mine and at Mineral belong to the same series, and there is, as far as could be seen, no line which separates it from the Paleozoic series of Weatherby and Durkee. The line indicated on the map is really arbitrary. The only indication of its age obtainable were a few round crinoid stems from the limestone near the gypsum mine at Huntington. I incline to the belief that this series is Triassic, in spite of the lack of distinct separation from the older rocks, and base this belief on the flat dip and on its association with large amounts of volcanic rocks, so characteristic of the Triassic of this region.

TRIASSIC SEDIMENTS.

The Triassic beds found in the United States may be grouped in two widely differing areas. The first include the Red Beds of the eastern part of the Cordilleran system, and consist of a considerable thickness of sandy strata in which fossils are very scarce and which probably are not of marine origin. The Triassic beds of the Pacific slope are of very different character, being distinctly marine sediments and generally containing characteristic fossils. The fauna is similar to that of the Alpine province in Europe. The first marine Trias was discovered by Whitney in California, and was examined by Gabb, who identified it with the upper Trias of the Alps. Soon afterward thick Triassic strata were discovered in the Star Peak Range, Nevada, by the geologists of the Fortieth Parallel Survey; and later, Triassic beds with a thickness of several thousand feet were found by Dr. C. A. White[1] in southeastern Idaho. The Triassic beds of California have been described by Professor Hyatt[2] and J. Perrin Smith.[3] The latter, in a recent article, has given an excellent review of our knowledge of the marine Trias of the Pacific coast and its correlation with European and Asiatic occurrences. The Canadian geologists have also discovered beds of similar age and character in British Columbia. Professor Dawson,[4] in 1899, described an extensive Triassic series associated with surface lavas of the same age from the vicinity of Nicola Lake, and named it the Nicola formation. Further discoveries of marine Trias have been made on Peace River and near Glenora, on the Stikine River. McConnell has found Triassic beds on the Liard River, and Dawson again found Triassic beds on Queen Charlotte Island and several other islands in the Straits of Georgia. Still farther north, in the Copper River region of Alaska, the Triassic has recently been identified by Messrs. Schrader and Spencer.

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[1] Geologic Atlas U. S., folio 66, Colfax, California.

With widespread Triassic areas in California, Idaho, and Nevada, and with similar areas north of the international boundary line, it seemed strange that no rocks of the same age were found in Oregon or in Washington. This gap has been partly bridged by the discovery of very extensive Triassic beds in the Eagle Creek Range, extending from there across Snake River into Idaho, to the vicinity of the Seven Devils. If the sedimentary rocks in the vicinity of Huntington belong to the same age, as is possible, though by no means certain, the area of the Triassic would be still further extended.

A characteristic feature of the Triassic of the Eagle Creek Range is the occurrence of large masses of limestone and some shale, with an abundance of more or less altered lavas poured out during the time when these beds were being deposited.

The Triassic sediments are best exposed on Eagle Creek. All along the foothills of the lower Powder River the Triassic lavas contain smaller bodies of limestone and shale, but on Eagle Creek, below the forks, the sedimentary series prevails and consists of calcareous shales and limestone in horizontal or slightly inclined position. Volcanic breccias are interbedded with the limestone. The total thickness of the series, including the volcanic beds, is probably several thousand feet. Many of the exposed limestone masses are several hundred feet in thickness. Above the junction, as described on page 735, the limestones become converted into marbles and the volcanic breccias into schists, while the whole series acquires a dip of 60° eastward.

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[1] U. S. Geog. and Geol. Surv. of Terr., 1883, Vol. XII, Pt. I, p. 105.

[2] Bull. Geol. Soc. America, Vol. V, p. 395.

[3] Jour. Geol., Vol. VI, 1898, p 776.

[4] Descriptive Sketch of the Dominion of Canada, by G. M. Dawson: Montreal, Canada, 1879.

Dr. T. W. Stanton examined fossils collected one-third mile below the mouth of East Eagle Creek, and reports them to consist of numerous specimens of *Halobia* and two indeterminable fragments of an ammonite. The *Halobia* is apparently an undescribed species, but the genus itself is characteristic of the Trias. Another lot, collected from the limestone bluff on East Eagle Creek 2½ miles above its mouth, contains *Pentacrinus* columns with spines and fragments of tests of echinoids. From the Miles placers, 1½ miles below the mouth of East Eagle Creek, I obtained, through Mr. F. R. Mellis, of Baker City, a cast of a gigantic gasteropod found in the limestone bed rock during drifting operations on this claim. Dr. Stanton remarks that it has the form of a very large *Turritella* or *Pseudomelania*. Nothing of this character approaching it in size has been described from the west coast, but similar forms described as *Chemnitzia* and *Pseudomelania* are known from the Trias and Jura of Europe. The total length of this cast is 8 inches and its diameter at the thickest end 3 inches.

Along Snake River Canyon, below the mouth of Pine Creek, Triassic lavas and tuffs are again exposed in the bluff below the Neocene basalt flows which cap the hills. These Triassic igneous rocks contain thin beds of black shales and limestone with imprints of a large species of *Daonella* or *Halobia*. A limestone mass 4 miles below Ballard Ferry contained a *Lima* with fragmentary imprints of a *Halobia* (?), and is also probably Triassic. The last two fossils were obtained from Mr. E. Antz, of Ballard Ferry.

From these data and from what is known of the field relations of the strata it is safe to conclude that a Triassic series is developed on a large scale in this region; but from the paleontological evidence at hand it would not be possible to say which one of the numerous subdivisions of the series is present. The Eagle Creek Mountains offer a most attractive field for future study.

TRIASSIC LAVAS.

Extending from North Powder to Eagle Creek along the foothills of the range are large areas of old basalts, andesites, and tuffs, containing in places small masses of limestone and shales. Though greatly altered, they are as a rule not schistose, except in the central part of the Eagle Creek Mountains. Fine-grained uralitic metabasalts were found in the Farley Hills. Near Copper Butte and the claims of the North American Copper Company dark-green or brownish amygdaloid metabasalts and tuffs, often full of calcite nodules and veinlets of zeolites, were collected. Similar altered basalts, andesites, and rhyolites, with their tuffs, were found at many places along Snake River below Pine Creek. Some of these are described in more detail on pp. 731 and 750. At the Sheep Rock mine, on East Eagle Creek, below the Triassic limestone, appears a volcanic breccia of metabasalt and other lavas, which also contains fragments of a granitic rock. A few miles higher up this breccia becomes very schistose. Its original character is not apparent to the naked eye, but the microscope reveals it very plainly. The fragments of lava are pressed flat or lenticular, and secondary hornblende and chlorite suffuses the whole rock.

JURASSIC AND CRETACEOUS SEDIMENTS.

Neither Jurassic nor Cretaceous sediments have been recognized in the area described; but from the Crooked River drainage, west of Blue Mountains, a sandstone with characteristic Jurassic fossils was collected by Prof. Th. Condon, of Eugene, Oreg., and examined by Professor Hyatt.[1] The Chico Cretaceous with its characteristic fossils has been found by Professor Condon at many points in the Crooked River drainage and along the lower John Day River.[2] Lately Dr. Merriam has visited the same region and recognized, besides the Chico Cretaceous, beds possibly belonging to the Knoxville or Lower Cretaceous.

NEOCENE SEDIMENTS.

During the Neocene period most important changes took place in the Blue Mountains. The volcanic flows radically changed the topographic features of the lower slopes; the upper river valleys were dammed and filled with silts and gravels; the upper Snake River Valley became a lake, dammed by the lava barriers extending from the Idaho Mountains to the Cascades, and its surface attained a level corresponding to a present elevation of approximately 4,200 feet. This lake has left abundant traces of its existence throughout the Snake River Valley, particularly between Boise and Weiser and on both sides of the Owyhee Range. The rising waters of the lake followed the river valleys draining toward it far into the mountains, where remains of its deposits may still be found. Surrounding the margin of the lakes are many small, basin-like depressions, which in part are certainly of structural origin—that is, caused by depressions along certain fault lines. These basins are usually filled with lake sediments. As the lake gradually receded, accumulations of gravels followed the retreating waters in the old river valleys, and these now form terraces resting on the lake beds.

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[1] Trias and Jura in the Western States: Bull. Geol. Soc. Am., Vol. V, p. 395.

[2] Th. Condon, in Raymond's Statistics of Mines and Mining, Washington, 1870, p. 212. J. S. Diller, Bull. Geol. Soc. America, Vol. IV, p. 214.

Besides the highest stage of 4,200 feet, another prominent level is noted at a present elevation of about 3,000 feet. The older beds are considered of early Neocene age (Miocene), and have been called the Payette formation. The beds deposited at the lower stage have been called the Idaho formation, and are believed to be of late Neocene age (Pliocene). In the Payette formation the age has been determined chiefly from plant remains; in the Idaho formation from mammalian remains.[1]

The gravels and sediments of the Burnt River Valley above Bridgeport, of the Clifford Valley on the same river, of the Sumpter Valley, of the John Day Valley, and of the headwaters of the North Fork of John Day were all clearly deposited after the lava flows had dammed the lower course of the rivers. No fossils have been found in them. Being deposited shortly after the volcanic eruption they may confidently be regarded as of Middle Neocene age.

Along the slopes toward Snake River Valley traces of the great lake are noted from many places. The most interesting locality is Rye Valley, on Dixie Creek, a tributary to Burnt River. A series of clays and sands here occupies the narrow valley, the bottom of which has an elevation of 3,200 feet, up to elevations of 3,500 feet, but the beds are greatly eroded and dip 14° W., so that at the time of their deposition they probably filled the valley to much greater depth. Toward the south they are covered by a basalt flow at an elevation of about 4,000 feet. This probably indicates the highest stand of the lake. No fossils were found in these beds. A series of gravel benches lies unconformably on these lake beds at elevations up to 200 feet above the bottom of the valley (3,200 to 3,400 feet above the sea). In these were found well-preserved teeth of *Mastodon americanus* and *Elephas columbi*, according to the determinations of Dr. F. A. Lucas. These species are characteristic of the early Pliocene.

Along Willow Creek, south of Malheur, a well-defined base-level is noted at an elevation of about 3,200 feet, probably indicating the stand of the Pliocene lake at that level. Willow Creek is sharply incised several hundred feet below this level, which is further marked by thin lake beds covered by a basalt flow. Long and shallow débris slopes extend from this level up to Malheur, at the foot of the slate ridge. From here to Huntington lake beds and basalts continue, until near the head of Durbin Creek another high level of deposition seems to be reached, at an elevation of 4,100 feet. This is not far from Rye Valley, and the basalt is the continuation of the area mentioned as beginning south of that place.

Another of the remarkable basin-like depressions along the margins of the lake is found at Durkee. Above and below, Burnt River flows in a narrow canyon. The valley itself is filled with lake beds. On the west side there are remains of a well-defined bench at an elevation of 3,100 feet. On the north the beds extend much higher up on the slopes of Lookout Mountain, probably reaching 4,000 feet. They are disturbed, dipping gently westward, and are interstratified with rhyclite tuffs and covered in places by small basalt flows.

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[1] Twentieth Ann. Rept. U. S. Geol. Survey, Part III, 1900, p. 97.

The divide between Burnt River and Powder River along the railroad shows most interesting relations. At the summit, which has an elevation of 4,000 feet, is a gap 2 or 3 miles wide, bounded on both sides by low slate hills. The rolling hills are covered with shallow, gently folded lake beds, dipping 12° to 30° E. or W.

The gravel slopes on both sides give positive evidence that an elevation of 4,100 or 4,200 feet marks an old and important base-level. I can see no other explanation possible than this: That the Payette Lake once just covered the summit and the basin of Sutton Creek. Whether the Payette Lake also flooded Baker Valley is doubtful. There seems to have existed a very delicately balanced set of conditions which finally caused Powder River to turn northward and excavate the canyon south of Baker City in the basaltic barrier extending across from the Virtue Hills to the Elkhorn Range. This barrier was originally probably just a little higher than the gap through which the railroad runs.

PLEISTOCENE SEDIMENTS.

Older sediments.—As elsewhere in the Pacific States, there is no distinct line separating the Neocene and the Pleistocene sediments. The two periods insensibly grade one into the other. Assuming that the highest level of the Neocene lake in Idaho marks the middle of that period, equivalent to the Miocene, it follows that the excavation of the great Snake River Canyon comprises the late Neocene (Pliocene) and probably a part of the Pleistocene period. It has been assumed, on the basis of paleontological evidence, that the next lower level of the lake, at an elevation of about 3,100 feet, marks the close of the Pliocene and that the erosion of the Snake River Canyon below that level falls into the Pleistocene.[1] The Glacial epoch then merely becomes a part—and a smaller part—of the Pleistocene period. As a result of this reasoning, the gravel bars along the lower courses of Snake, Powder, and Burnt rivers, up to an elevation of several hundred feet above the present bed, may be assigned to the Pleistocene. But as the tributary streams are ascended, erosion has cut down less deeply into their beds, and Neocene gravels may in places be found at 50 feet, or even less, above the present river level—as, for instance, in the upper Burnt River and Powder River valleys. On the John Day side, as would be expected from the lower level of the Columbia River, erosion has been more active than on the side facing the upper Snake River Valley. Throughout the whole region the rivers and creeks usually flow over gravel-filled beds, indicating a present slow rate of progress of erosion.

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[1] Twentieth Ann. Rept. U. S. Geol. Survey, Part III, 1900, p. 101.

To the Pleistocene period belong also the alluvial deposits in Baker, Pine, and Eagle valleys.

The largest Pleistocene area is that of Baker Valley, an elliptical trough 20 miles long and 10 miles wide. Excepting near the foot of the Elkhorn Range, where large and gently sloping débris fans mark the debouchure of the gulches, it is a remarkably level area. Above and below the valley the river flows in canyons. Interesting evidence has been adduced which proves that a fault line exists along the foot of the Elkhorn Range (p. 652) and that the whole valley is probably a field of depression, similar to so many of the basins in the marginal areas of the great Payette Lake. If the erosion of the lower canyon near North Powder did not keep pace with the sinking along the fault line, Baker Valley must, at some time during the Pleistocene, have been a shallow lake. The only definite evidence of this is the fine-grained kaolinic material capping the gravels in the lower reaches of the creeks at the foot of the Elkhorn Range. At Baker City wells are said to have been drilled through sediments to a depth of 600 feet. Carbonized wood and other vegetable remains are reported to have been brought up from that depth. This shows clearly that the Pleistocene of the valley rests in a closed basin.

Glacial deposits.—It has been shown by Prof. I. C. Russell and myself that during a late part of the Pleistocene period, probably during the Glacial epoch, the canyons of Snake and Salmon rivers were again filled with sediments to a depth of about 300 feet and that the erosion since the close of that epoch has been limited to the removal of these 300 feet of sediments, together with an insignificant deepening of the early Pleistocene rock channel. Between Mineral and Connor creeks, in the upper Snake River Canyon, are indications of a similar filling of the eroded canyon by sand to a similar depth, 300 feet. Aside from this there are few gravel bars higher than 50 feet above the present river bed.

INTRUSIVE ROCKS.

Granite.—True orthoclase granites appear to be absent from the area examined. At least no well-marked occurrences of this rock were found. The granitic area of Sparta consists of a normal soda granite in which the orthoclase is almost entirely wanting, its place being filled by albite. The surface of this granite area is extremely decomposed, and fresh rock can be obtained only from shafts and tunnels. A representative specimen from the Gem mine is a greenish-gray rock, with grains averaging 3 mm. to 5 mm. in diameter. The quartz grains are abundant and large, the feldspars slightly greenish. There are only small amounts of ferromagnesian minerals, mostly chlorite. The thin section shows a very large amount of quartz and a smaller amount of feldspars. Some of these are prismatic crystals, others irregular grains. A number of the feldspars are single crystals; others show a few intercalated lamellæ, the maximum extinction of which in the zone perpendicular to (010) is about 14°, corresponding to albite. No perthite is present. Between the quartz and the feldspar is a little chlorite, probably remains of primary biotite.

A partial analysis of this granite by Dr. W. F. Hillebrand resulted as follows:

Analysis of granite from Sparta.

Constituent.	Per cent.
SiO_2	76.25
CaO	1.70
Na_2O	4.60
K_2O	.59

This indicates a very unusually pure albite-granite containing a large amount of quartz.

In the first foothills west of Sparta and north of Powder River the granite becomes porphyritic by the development of large quartz crystals. This granite-porphyry has a coarsely microcrystalline groundmass of pegmatitic quartz, and much albite and some orthoclase, the latter two in part intergrown in the manner of perthite.

Granodiorite.—The most common granular rock of eastern Oregon is granodiorite. It occupies a large area in the northern part of the Elkhorn Range, including Bald Mountain. It also appears near Cornucopia, in the Eagle Creek Range, and, together with diorite, in the several areas extending from Lookout Mountain to Malheur. The rock is light gray to dark gray in color and its grains are from 2 mm. to 4 mm. in diameter. The quartz grains are gray, the feldspars white; the hornblende, which is usually present, appears in prisms up to 6 mm. long. The biotite, which is always present, forms black scales up to 3 mm. in diameter. Under the microscope the rock has a hypidiomorphic structure. The biotite appears in yellowish-brown, ragged foils, inclosing much magnetite. The most abundant feldspar is a roughly prismatic andesine, embedded in the usual way in anhedral clear quartz and orthoclase. Perthite and microcline are absent. The rock is never schistose and is usually fresh. Only a slight alteration to chlorite and epidote is noticeable in the biotite and hornblende.

A typical rock from near the lake at the northern base of Bald

Mountain, at an elevation of 7,000 feet, was analyzed by Dr. W. F. Hillebrand with the following result:

Analysis of granodiorite from Bald Mountain.

Constituent.	Per cent.
SiO_2	71.23
Al_2O_3	14.61
Fe_2O_3	.93
FeO	1.66
MgO	1.01
CaO	3.29
Na_2O	4.00
K_2O	1.92
H_2O (below 110°)	.17
H_2O (above 110°)	.55
TiO_2	.34
ZrO_2	.02
P_2O_5	.14
MnO	.08
BaO	.08
SrO	.02
Li_2O	Trace.
Total	100.05

The analysis shows that the rock is a normal granodiorite of an acid type, containing a little more quartz than is usual in the granodiorite of the Sierra Nevada.[1] For this reason the other constituents appear with slightly lower percentages than they would have in a rock poorer in quartz. In the small areas and near the contacts of the large areas the rock shows a great tendency to transition into normal diorite. Examples of this may be seen near the Baisley-Elkhorn mine, at the divide between Powder River and Bull Run, on the road from Sumpter to Granite, in the Greenhorn Mountains, and at many other places.

Diorite.—The diorite, which occurs as a facies or local development of granodiorite, is a dark-gray to dark-green granular rock, consisting of andesine or labradorite feldspar, greenish hornblende, and sometimes brown biotite, with magnetite and titanite as accessories. The hornblende is usually roughly idiomorphic, as are, with short prismatic form, the feldspars. Pressed in between the feldspars is frequently a little quartz. Diorites were collected from the Baisley-Elkhorn mine, from the Coyote Hills near Haines, and from Dixie Creek Canyon above Prairie. Diorites containing some orthoclase were collected from the Powder River Canyon near North Powder.

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[1] Granodiorite and other intermediate rocks, by W. Lindgren; Am. Jour. Sci., 4th series, Vol. IX, p. 277.

Gabbro.—The dioritic rocks are sometimes intimately associated with gabbros. It is thus, for instance, in the Robinsonville and in the Virtue districts. The gabbros are greenish-gray granular rocks, composed chiefly of a basic plagioclase and a pyroxene often converted into uralitic hornblende. The gabbros of this region are often irregularly crushed, but rarely schistose. Gabbro areas are found in the Virtue district, in the Elkhorn Range, in the Greenhorn Mountains, and finally near Canyon. In the latter two localities the rock is associated with large areas of serpentine.

A gabbro from the Flagstaff mine, Virtue district, is a mottled, dark greenish-gray rock, much crushed and recemented, but not schistose. The feldspars are saussuritic, of almost flinty appearance. The rock consists of coarse aggregates of light-green amphibole, which also pervades the whole slide in needles and fibers. The originally large grains of plagioclase, which stands between labradorite and anorthite, show extraordinary bends and fractures in their broad twin lamellæ, and are dissolving into new aggregates of basic feldspar. There is no zoisite present. A uralite-gabbro containing much zoisite was collected from the Copper King mine, 7 miles west of North Powder.

One mile below the Little Giant mine, near Alamo, two rocks closely associated with serpentine were collected. One of these is a coarse gabbro crushed almost to a breccia, and containing serpentine and chlorite on the fractures. The other is a fine-grained aggregate of anhedral, light-brownish hornblende, with an andesine or labradorite. At the Virginia mine, Robinsonville, occurs, closely associated with serpentine, a greenish-gray, granular rock of somewhat varying grain, the maximum being 2 mm. The rock originally consisted of colorless augite and basic plagioclase, with typical gabbro structure, but it is extremely crushed, the augites are bent and shattered, and the plagioclase is filled with sericite and traversed by veinlets of calcite and zoisite. At the Great Northern mine, near Canyon, gabbro also appears, associated with diabase and serpentine. The rock is a normal gabbro consisting of broad anhedral grains of augite and basic feldspar; it is greatly altered and filled with chlorite, uralite, and kaolin.

Diabase.—The diabases are granular rocks belonging to the gabbro family and consisting of augite and labradorite feldspar, intergrown with peculiar and characteristic structure. Typical diabases are not very common in this region. Diabases form the prevailing rock of the Quartzburg district and are adjoined on the south, below Comer, by diorites. At the junction of the two forks of Dixie Creek appears a very fresh, dark-green diabase-porphyry, with abundant phenocrysts of uralitized augite and plagioclase in a somewhat finer-grained groundmass of normal uralitized diabase. Near the Present Need mine coarse diabases are found associated with dikes (?) of diorite-porphyry. Similar uralite-diabases are found at Copperopolis, on the east fork of Dixie Creek.

At the Great Northern mine irregular masses of a very altered diabase occur in the gabbro. The rock is filled with calcite and chlorite, only the lath-like feldspar remaining fresh.

Serpentine.—This rock, which is rarely found in Idaho and Montana, begins to appear in force as the Pacific province of intrusive rocks is reached. It forms large areas in the vicinity of Robinsonville and Bonanza, in the eastern part of the Greenhorn Mountains, at Susanville, and in the Strawberry Range south of Prairie and Canyon. At all these places it is closely associated with gabbros and allied rocks. This is so constant that one is forced to believe that the serpentine is an altered form of gabbro, perhaps also of peridotites, and that in its original state it was intruded simultaneously with the gabbros, diorites, and granodiorites into the sedimentary series.

The serpentine is of the ordinary dull-green appearance, and has not suffered greatly from pressure. Thin sections from Canyon show a normal rock with grate structure, containing abundant magnetite, forming a network in the clear serpentine mass. Chromite is found in the serpentine south of Prairie and near the Winterville placer mines.

The older dike rocks.—The sedimentary series and the granular rocks intrusive in them do not contain many dikes. Between Sumpter and the North Pole mine several greatly altered and partly mineralized dikes, which probably originally were diorite-porphyries, cut the argillites. Aplites are sometimes found near the contact of the intrusives, as are minor dikes of diorite and granodiorite. Porphyry dikes of light color, completely altered, bleached, and softened, occur in the Red Boy mine. In the Coyote Hills the diorite contains pegmatitic dikes consisting of orthoclase, microcline, and quartz, together with some idiomorphic andesine and small grains of augites—a very unusual character of pegmatite. In the same locality were found fine-grained dioritic dikes of the kersantite type of lamprophyres, a class of rocks which otherwise seem very rare in this region. In Idaho it has often been observed that gold-quartz veins follow such narrow lamprophyric dikes. The only similar occurrence in the Blue Mountains is at the Connor Creek mine, where a narrow dike of sericiticized and carbonatized porphyry accompanies the vein.

NEOCENE LAVAS.

General statement.—The Neocene period in the Blue Mountain region, as throughout the whole of Oregon, Washington, and California, was characterized by enormous eruptions of lavas of different kinds. So far as known the Neocene lavas of the Blue Mountains belong, almost without exception, to the earlier part of the Neocene period—that is, to the Miocene. Late Neocene (Pliocene) and even Pleistocene eruptions are known to have taken place in different parts of the Northwestern States, but in this region it seems as if the Pliocene epoch had been one of quiescence as far as eruptions were concerned. The Neocene lavas surround the Blue Mountains almost completely. They fill the old valleys of a drainage system occupying a lower level than that of the present streams. The highest parts of the Blue Mountains are, as a rule, not covered with these flows, but on the lower slopes they are piled up in numberless sheets, aggregating as much as 2,000 feet in thickness.

The rocks of this series are separated into three groups—the basalts, the rhyolites, and the andesites. The basalts are the most widely distributed of the rocks, but the rhyolites and the andesites also occupy large areas.[1]

Regarding the succession of these lavas, the evidence is not altogether satisfactory. South of Baker City and near Durkee the basalts cover rhyolitic tuffs. On the divide between Powder River and Burnt River, south of Baker City, the basalts also seem to rest against older masses of rhyolite. On the other hand, near Canyon basalt flows appear to be overlain by rhyolite tuffs, and on the flanks of Strawberry Butte a dike of rhyolite apparently cuts the basalt flows.[2] Near Austin basaltic flows seem to cover the andesite. It will be seen that the evidence is somewhat contradictory, but, on the whole, it seems probable that the eruptions were begun by rhyolites, followed by andesites, and closed by the basaltic outbursts. Near Boise, in the adjoining region of Idaho, the rhyolites were the earliest of the Neocene eruptives, and were succeeded by a basalt. In the Silver City district, in southwestern Idaho, on the other hand, the rhyolite is later than the basalt, as is clearly seen in the section of the Trade Dollar mine.[3]

Rhyolite.—The rhyolites are generally absent from the eastern and western parts of the area described. The largest rhyolitic eruption is found south of Baker City, where it builds up the divide between Powder River and Burnt River from a point some miles west of Hereford down to the mouth of Clarks Creek. The hills north of Burnt River consist almost entirely of rhyolite. The same rock continues up to the divide, 2,500 feet above the river, and down the northern slope toward Powder River until at an elevation of 5,000 feet (1,000 feet below the summit) the covering basalt flows are met with. Toward the east this rhyolite gradually thins out, and near Pleasant Valley only a few small areas are found covering the slates. Rhyolite tuffs occur, as stated, near Baker City, on Griffin Gulch and Sutton Creek, also near North Powder, on Wolf Creek, and finally at Canyon.

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[1] A valuable contribution to the literature of the lake beds and eruptive rocks of the lower John Day River has recently been published by Dr. J. C. Merriam. (University of California, Bull. Dept. Geol., Vol. 2, No. 9, pp. 269-314.) He finds in the John Day River Basin, below Canyon, the following formations: (1) Eocene lake beds, with flows of rhyolite and andesite (Clarno formation); (2) John Day series (Miocene) of tuffs, with several flows of rhyolites; (3) Columbia River lava (Miocene basalts); thickness over 1,000 feet; (4) Mascall formation (probably Miocene) of tuffs and ashes; (5) Rattlesnake formation (probably Pliocene), consisting of gravels, tuffs, and rhyolite, the latter overlying Columbia River basalt; (6) Terraces (Pleistocene) up to 100 feet above the rivers.

[2] These rhyolites of Canyon are evidently identical with those in the Rattlesnake formation of Dr. Merriam, which he regards as of Pliocene age. See footnote 1, above.

[3] Twentieth Ann. Rept. U. S. Geol. Survey, Part III, 1900, p. 140.

The rhyolite is of the normal reddish or brownish lithoidal variety, with small crystals of feldspar and quartz contained in a streaky microcrystalline to cryptocrystalline groundmass. The rhyolite tuffs are light-colored, grayish rocks, which usually are easily dressed, and therefore make good building stone. They consist of a mass of rhyolitic fragments, often pumice-like in character, and cemented by a finer mass of the same material.

Dacite.—A few miles north of Hereford, on Big Creek, occurs a flow of light-brownish rock closely associated with the rhyolite. It contains abundant porphyritic crystals of quartz, glassy feldspar, and brown biotite in a hypocrystalline groundmass of trachytic structure. The feldspars are a plagioclase approximating to labradorite in composition, and the rock should therefore be classed as a dacite.

Andesite.—Andesites are practically absent from the whole eastern and northern part of the area described. At Granite and in Bull Run, for a few miles above the town, however, bluffs of hornblende-andesite appear on both sides of the stream, apparently covered by basalt. The thickness attained is only from 50 to 100 feet. The rock is light gray and porphyritic, containing small phenocrysts of feldspar and hornblende in a fine-grained groundmass consisting of plagioclase and hornblende. The structure of the groundmass is trachytic. The feldspar phenocrysts are apparently labradorite. In their largest development the andesites are found on the headwaters of Burnt River and on the divide between that river and the Middle Fork of John Day. They even extend as far west as Prairie, near which place they are apparently covered by later basaltic flows. The andesitic eruptions in the vicinity of Clifford have a thickness of probably not less than 1,000 feet, and form a greatly dissected plateau, the summit of which attains an elevation of from 5,000 to 6,000 feet. To a very large extent the andesites are of fragmental character—that is to say, they consist of tuffs and breccias. On the road from Sumpter to Hereford the divide between Powder River and Burnt River is covered by 300 feet of andesitic tuffs and breccias well stratified, coarser layers alternating with more fine-grained material, almost like sandstones. These tuffs dip 20° N., and at the summit of the ridge have an elevation of 5,500 feet. On the south side of the ridge andesitic breccias prevail down to an elevation of 4,500 feet, when the underlying rhyolites appear, covered by dacite. West of Burnt River the heavy flow which extends down toward Susanville and Prairie consists very largely of coarse breccias, containing angular fragments of andesites of varying appearance. Some are dark gray; others brownish or black. Many fragments are vesicular. This breccia is cemented by a finer mass of the same material, and the whole forms a well-consolidated mass. The resemblance to the andesitic breccias overlying the auriferous gravels in California is very striking.

The rocks are chiefly normal hypersthene-andesites, containing phenocrysts of labradorite, augite, and hypersthene inclosed in a brownish, glassy groundmass containing small needles and prisms of feldspar. Sometimes fragments of lighter color are present which contain, besides augite and pyroxene, some needles of hornblende.

Basalt.—As is well known, basalt is the predominating rock among the eruptive masses surrounding the Blue Mountains. Basalt flows cover vast areas in the eastern part of the region described, adjoining Snake River, where they form the extensive plateau which almost completely surrounds the Eagle Creek Mountains. Throughout the larger part of this area the basaltic formation consists of a great number of superimposed flows which are well exposed along many sharply incised canyons. The flows are from 50 to 150 feet thick, and slight differences in weathering render them very conspicuous in favorable exposures. East of Cornucopia the basaltic flows reach a total thickness of over 2,000 feet; only rarely are they accompanied by or interbedded with tuffs. This formation, with its characteristic exposures of thin, superimposed beds of dark-brown color, extends over thousands of square miles north, east, and west of the Eagle Creek Mountains. It is the same formation which Prof. I. C. Russell has named the Columbia River lava, and it must be acknowledged that the persistent extent of these beds over such a vast territory deserves to be specially pointed out by a local name. If this name is to be preserved as a distinct formation name, I would suggest that it be restricted to the basaltic lavas of Miocene age. It seems to be the intention of Professor Russell to give it a somewhat wider significance, including under it different kinds of lava of Miocene or Pliocene age. This seems scarcely advisable if the name is to be preserved in the significance given to it above. The Columbia River lava crosses Powder River just south of Baker City and appears on the low hills separating the upper from the lower river. The flows are here very thin, rest on clays, sands, and fine gravels, and slope gently eastward.

Little Lookout Mountain is covered by a succession of basalt flows evidently belonging to the same formation. Similar rocks are exposed in Burnt River Valley, between Weatherby and Durkee, and on the spur between Rock Creek and Snake River. On the Idaho side the characteristic flows descend to river level, showing that the canyon must have been excavated before the period of basaltic flows.

The Elkhorn Range from Auburn north is free from basalts and other Neocene eruptions, but at its southern end, in the first sharp bend of Powder River, south of Baker City, basaltic flows are piled up to an elevation of 4,700 feet, or a total thickness of about 1,000 feet. Heavy masses of basalt form bluffs on both sides of Granite Creek, below the town of Granite, and extend from here nearly up to the summits of the Greenhorn Range.

Basaltic flows are again noted near Austin and on the lower slopes of the John Day Valley from Prairie to Canyon. They are beautifully exposed on Strawberry Butte, south of Prairie, and it is probable that the headwaters of this river are entirely surrounded by these igneous masses. On Strawberry Butte the total thickness of the flows probably amounts to several thousand feet. As in the southern portion of the area, individual flows are well exposed, appearing as dark-brown strata on the abrupt slopes of the mountain.

In petrographic character the basalts show little variation. They are entirely normal rocks of their kind, with or without olivine, and ordinarily contain a moderate amount of glassy groundmass. Occasionally, however, this glassy base almost disappears, and the rock then is usually somewhat coarser, having the appearance of a diabasic rock. Vesicular and massive flows alternate; the former are usually the more glassy varieties. From near the mouth of Canyon Creek, at the town of John Day, was collected a black, fine-grained basalt of unusual freshness. It contains nearly lath-shaped crystals of labradorite, abundant fresh, small olivine grains, and a brownish augite. These constituents are cemented by a small amount of dark-brown glass containing very beautiful arborescent forms of magnetite. A short distance north of Medical Springs (20 miles north-northeast of Baker City) the rocks are very unusually glassy basalts. Thin sections show them to consist chiefly of glass filled with minute crystals of pyroxene and a few larger phenocrysts of plagioclase. The rocks also contain a few larger prisms of hypersthene.

The question of the manner of eruption of these enormous masses of basalt has always been an interesting one. It is generally believed that the magma was not ejected from volcanoes, but that it poured out in a comparatively quiet manner from large fissures in the crust. This view has been substantiated by the discovery of a large number of basalt dikes at Cornucopia and other places high up on the flanks of the mountain, and in such a position relative to the flows that it is not to be doubted that the foci of the eruption were located at these places. A description of this interesting occurrence will be found under the head of Cornucopia mining district. The rocks collected from dikes prove in all cases to be normal basalts containing a varying but generally small proportion of glass. Basalt dikes were also found at Mineral, Idaho, at Sparta, and on the road from Rye Valley to Mormon Basin; but in no place are they exposed on such a magnificent scale as in the Bonanza Basin, near Cornucopia.

GEOLOGICAL HISTORY.

The oldest rocks of the Blue Mountains are represented by the relatively small area of gneiss embedded in the granodiorite north of Bald Mountain. Undoubted Archean gneiss is not often met with in the Pacific States. Mr. H. W. Turner[1] has described areas of probable Archean gneiss from the Big Trees quadrangle, Calaveras County, Cal. This area is embedded in granitic rocks of much later date. In Idaho, along the Nez Percé trail, north of Salmon River, two large areas of gneiss were found[2]—one near Shoup, the other at Elk City. Both have the appearance of true Archean gneisses and both are shattered by later granites. These isolated occurrences are of much interest, as they indicate the character of the basement upon which the Paleozoic rocks were deposited. The composition of the Oregon gneiss probably indicates a sedimentary origin, but it is completely recrystallized over a large area, which precludes the supposition of contact-metamorphic origin. Unfortunately, no contacts between the gneiss and the sedimentary rocks were observed; but it is likely that the latter were deposited unconformably upon the gneisses.

During the Paleozoic age the sea extended over what is now the Blue Mountains and probably connected with the Carboniferous sea of eastern Nevada and California. The deposits of this sea consisted of argillaceous and siliceous mud, which during long subsequent ages consolidated to argillites, more or less rich in silica. These were the prevailing sediments, but a few interbedded strata of limestone were also formed, the largest appearing now in the hills west of Durkee. The sediments contain interbedded volcanic rocks (tuffs and greenstones) in a few places, but they are not prominent. The only clue to the age is furnished by the round crinoid stems in the limestone of Winterville. This argillite series is undoubtedly older than the Trias of the Eagle Creek Mountains, and may without much uncertainty be referred to the Paleozoic, possibly to the Carboniferous, which is so extensively developed in California. The whole argillite series, from Weatherby to the Greenhorn Mountains, is composed of fine-grained sediments, indicating deposition in deep waters. Sandstones, quartzites, and conglomerates are entirely absent, according to present information.

This probably Paleozoic series is adjoined, toward Huntington, by another series of clay slates, shales, and limestones, with some gypsum. At Huntington these sediments rest with flat dip on heavy masses of old lavas and tuffs, which now are considerably altered, though nowhere schistose. The general character of this series shows much similarity to the Trias of the Eagle Creek Range; on the other hand, toward the northwest these rocks soon change into the steeply dipping argillites of the Burnt River Canyon above Durkee, which have been considered as Paleozoic. No contact line or unconformity could be observed, and the whole series dips northward. The line drawn on the map is wholly arbitrary and may have to be revised. Indeterminable fossils, some of which seemed to be round crinoid stems, were found in the Huntington series near the gypsum quarry.

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[1] Geologic Atlas U. S., folio 51, Big Trees, California.

[2] Unpublished notes, W. L.

The structural features show considerable regularity. The argillites of the Elkhorn Range trend a few degrees north of west and dip about 60° S. South of Burnt River Canyon and as far down as Huntington the strike is southwesterly or south-southwesterly, the dip generally being at steep angles toward the north. Thus it would seem that the sediments are folded, roughly speaking, into one great geosyncline. Strongly marked slaty cleavage is generally absent, though in a few places in the Elkhorn Range are indications of joints and cleavage planes perpendicular to the stratification. In many places the argillites are massive and fail to show the direction of the stratification. The thickness of the argillite series can not be safely estimated at present; it doubtless amounts to several thousand feet.

During the Triassic period the ocean again covered this region, though the abundance of surface lavas and tuffs indicates that the waters were shallow and land masses not far distant.

The Triassic of the Eagle Creek Mountains and Snake River consists of shales and limestones interstratified with a vast amount of more or less altered tuffs and lavas, and is exposed all along the lower Powder River and the upper course of Eagle Creek. There is reason to believe that these Triassic lavas extend as far northwest as the Farley Hills and the greenstone areas west of the North Powder, and they certainly again emerge from below the basalt flows in the canyon of the Snake River, below the Seven Devils. In this canyon they contain smaller strata of shale and limestone with Triassic fossils. Tuffs and old lavas with intercalated sediments and limestones again appear in the mining district of the Seven Devils, on the Idaho side. Along Eagle Creek the little-altered limestones and shales contain *Daonella* and *Halobia*, as well as pentagonal crinoid stems and fragments of ammonites and echinoids. In the foothills the strata sometimes lie nearly horizontal, but in the Eagle Creek Range they quickly acquire an easterly dip and become greatly altered by dynamometamorphism. The limestones change to marbles, the volcanic tuffs to amphibolitic schists. The central parts of the Eagle Creek Mountains are built up of these altered Triassic rocks. Outside of this area the strata and the Triassic lavas show no evidence of compression or traces of schistosity, although the volcanic rocks may have been considerably altered by ordinary hydrometamorphism, producing epidote, chlorite, and zeolites. The thickness of the Triassic beds and accompanying volcanic rocks is considerable, but has not been directly measured. Without doubt the total amounts to several thousand feet.

Though the strata of known Triassic age were at no place observed in contact with the Paleozoic series, it is probable, from the general relations, that there is an unconformity between the two series of strata. This implies that there were pre-Triassic uplift and folding, and that the Triassic beds were laid down on the upturned edges of the Paleozoic strata. It is not unlikely that during this uplift the intrusions of the diorites and gabbros of the Virtue district and the southern Elkhorn Range occurred. Among the volcanic tuffs and breccias of the Trias fragments of quartz-diorites are found.

After the deposition of the Trias followed another and more extensive uplift, probably the same which affected the whole of the Pacific slope. Both the Triassic and the Paleozoic series were folded, though the former in places still lies nearly horizontal. The Trias was violently compressed in the area now occupied by the Eagle Creek Mountains. The uplift was accompanied by very extensive intrusions of granular rocks, and as these now appear in the highest parts of the mountains and as great erosion has since taken place, it follows that the Blue Mountains in Jurassic and early Cretaceous times must have been a range of imposing height. The intrusions consisted of granodiorites, diorites, gabbros, and peridotites, the latter now partly converted into serpentines. They extend over the whole area from the Eagle Creek Mountains to the Elkhorn and the Greenhorn ranges. The time of this great uplift is difficult to fix with exactness from the data at hand. It was certainly post-Triassic and pre-Neocene. Jurassic strata have been found on Crooked River, west of the Blue Mountains, and also near Burns, south of Crooked River,[1] but their relation to the older strata is not known. Sandstones of Chico age, underlain by Knoxville beds, have been found at several places on the lower John Day River,[2] under such circumstances as suggest that they may connect below the lavas of the Cascade Range with the Cretaceous of western Oregon. It seems probable then that, at least as far back as the Chico Cretaceous, the western foot of the Blue Mountains was skirted by the sea, and that the uplift and intrusion of the granular rocks are of pre-Chico age. In the Sierra Nevada the time of similar upheavals has been determined as post-Jurassic and pre-Chico, and thus it becomes probable that the disturbance in the two provinces took place about the same time. Regarding the form of the mountain range after the great uplift, we know little except that it had a general east-west direction. A very active erosion had worked on it for a long time, but had failed to reduce it to anything like gentle topographic outlines. That the pre-Neocene rivers had excavated their channels to a greater depth than the present streams is certain, for the lavas descend to the level of Snake River below Huntington, and that mighty stream flows for many miles on a basaltic bed. Take away the lava flows which cover the flanks of the Blue Mountains, and you would see rising to imposing heights, almost from sea level, and separated by a lower gap, two great, roughly circular mountain groups—the Eagle Creek Mountains and the Blue Mountains proper. They formed a projecting spur from the great crust-block of central Idaho, but did not connect directly with the Sierra Nevada.

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[1] Trias and Jura in the Western States, by A. Hyatt: Bull. Geol. Soc. America, Vol. V, p. 401.

[2] J. S. Diller: Bull. Geol. Soc. America, Vol. IV, p. 214. Oral communication by Dr. J. C. Merriam.

Then, as now, the Blue Mountains were seamed by gold and silver veins, and gold-bearing gravels accumulated in its valleys. The formation of the veins followed the great intrusions of granitic rocks, and may be placed in the Jurassic or early Cretaceous.

Such were the conditions when the great Neocene lava flows began to pour out from numberless fissures on the flank of the mountains. At first came rhyolites and andesites, then basalts in increasing volume. Lava streams covered each other in endless succession. The lower water courses became filled with basalts, damming the headwaters and creating lakes. The sharp slopes became sloping plateaus, and finally the Blue Mountains stood like islands in a basaltic sea, a salient of the Idaho mass, separated from it by the black surface of slowly cooling flows. The rivers had to adjust themselves to these new conditions and lay out their lower courses anew. Hence all these strangely changed river courses and sediment-filled upper basins which form such difficult problems in the geology of the Blue Mountains. The bar of lavas thrown across from the Idaho Mountains to the Cascades resulted in the formation of a great lake in the central Snake River Valley, the waters of which reached elevations of about 4,200 feet. Establishing an outlet through the present course of Snake River, the lake was gradually drained. The Pliocene and the early part of the Pleistocene period were times of active canyon erosion, with many temporary checks, resulting in the formation of benches and bars of gravel high above the present drainage level. One of the most difficult problems is the explanation of the present course of Snake River below Huntington. Certain parts of the canyon must have been excavated before the Neocene period, even if it was largely filled again by local basalt flows. Below the mouth of Powder River the Snake for a long distance flows over basalt, and it seems probable that the old canyon turned somewhat westward and found its way toward the Columbia closer to the Eagle Creek Range. The question is, What caused the post-basaltic river to lay out its course across the high plateau of lava and across the projecting shoulder of the Seven Devils, which attains at least 6,500 feet in elevation, and where the canyon now is correspondingly deep? It would seem as if a much more natural outlet could have been established across the Deschutes gap at the foot of the Cascades, or through the present Baker Valley and down the direction of the Grande Ronde River. Much more detailed examinations are necessary to explain these problems.

After the close of the Neocene, or even during the middle of that period, followed other orogenic movements of a less violent character. The lake beds of Durkee Valley, of the Sutton Creek Plateau, and of Rye Valley were thrown into gentle folds and also faulted. At Rye Valley undisturbed Pliocene river gravels cover lake beds of Miocene age which form a monocline dipping gently westward. Besides this, there is no doubt that slow epeirogenic movements of the crust took place in eastern Oregon in Neocene and post-Neocene times, but their exact nature and amount are doubtful. The pre-Neocene drainage was cut deeper than that of the present day, and hence it would seem likely that this region has suffered depression of considerable amount. It seems, indeed, impossible that the extrusion of such enormous masses of lavas over such a vast area should not be accompanied by slow continental movements of some kind. To such movements is probably also due the course of Snake River Canyon below Huntington, referred to above.

After the Pliocene and early Pleistocene epochs of erosion, the Sierran period of Le Conte,[1] during which the conditions of the present day were gradually established, followed the Glacial epoch, when the climate became much colder and glaciers covered the higher region of the Eagle Creek, the Elkhorn, and the Greenhorn ranges. But this was of relatively short duration as compared to the period of erosion. The glaciers have disappeared only very recently, not many thousand years ago. Compared to the glaciers of the Sierra Nevada and the Cascade Range, they were of small extent.

There is reason to believe that there is an old fault line located at the eastern foot of the Elkhorn Range and that Baker Valley is essentially an area of subsidence. At some time in the Pleistocene period renewed faulting occurred along this line, as is shown most convincingly by the exposures at the Nelson gravel mine, near the mouth of Salmon Creek (p. 653). What the total amount of this faulting is remains doubtful. A dislocation of at least 200 feet is shown by the exposures.

PHYSIOGRAPHIC PROBLEMS.

The Blue Mountains abound in physiographic problems caused by many changes in river courses due to the lava floods. A few of these have been briefly touched upon in the detailed part of this report and in the paragraph on Neocene sediments; but many of them, and the most important ones, among which is the origin of the Snake River Canyon, are still unsolved, and a rich field here remains for future work. This report, being principally limited to problems of economic geology, is very incomplete in respect to the physiographic branch of geology.

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[1] The Ozarkian and its significance in theoretical geology: Jour. Geol., Vol. VII, 1899, pp. 525-544.

CHAPTER III.

THE MINERAL DEPOSITS.

GENERAL STATEMENT.

A great variety of mineral deposits has been found in the Blue Mountains. They contain gold and silver veins, copper deposits, gold-bearing gravels, ores of iron, manganese, and chromium, coal, limestone, and gypsum. Many rocks are used for building stone, and mineral springs with useful medicinal qualities occur in widely separated places. Economically, the placers and the gold and silver veins are the most important and will be most fully treated. The gold and silver veins are so intimately connected that it is scarcely possible to separate them in a description of the region. They may, however, be divided into three groups—the gold veins, the gold-silver veins, and the silver veins.

PRIMARY GOLD AND SILVER DEPOSITS.

GENERAL CHARACTER.

The primary gold and silver deposits are, with few exceptions, normal fissure veins of a simple or composite character, carrying native gold, or sulphurets containing gold or silver or both native gold and sulphurets, in a gangue of quartz, more rarely calcite or dolomite. Sometimes the deposits contain also a notable percentage of lead, copper, or zinc, but ordinarily these metals are present only in subordinate quantities; and, on the other hand, the copper deposits are apt to contain a little silver and gold. Nevertheless, the two classes of deposits maintain their distinctive and separate characteristics.

GENERAL DISTRIBUTION.

Broadly speaking, the gold and silver veins occupy a belt 30 or 40 miles wide, beginning near the State boundary along Snake River and extending in a westerly direction for at least 100 miles. This area roughly coincides with the core of older rocks, the highest parts of the Blue Mountains, rising above the surrounding lava floods and late sediments. The accompanying map covers this area, but does not show quite the full extent toward the west, for gold placers are found on Long Creek and Cottonwood Creek, 18 miles west of Susanville, and isolated occurrences even farther west—as, for instance, at the Spanish Gulch placers, on Crooked River, 66 miles west-southwest of Canyon.

The principal deposits are in Baker and Grant counties, though some are found also in Union County and along the northern boundary of Malheur County.

When the distribution of the veins and vein systems, as shown on the map, is examined in detail, it appears at once that there is no well-defined and continuous belt of deposits extending across the whole auriferous area. What is found is a great number of local aggregations of veins, distributed without clearly apparent rule. In some districts the veins are scattered irregularly; in others there are local belts from 2 or 3 miles up to 15 miles in length. The Cornucopia, Sparta, and lower Burnt River districts may be selected as representatives of the former mode, while the long vein systems of Cracker Creek and Cable Cove show the latter arrangement. The region in which most of the important veins are concentrated extends from the Elkhorn mining district on the east for 35 miles in a west-southwest direction to the Greenhorn Mountains.

DIRECTIONS OF STRIKE AND DIP.

The prevailing direction of the fissures in and along which the precious metals have been deposited is northeast and southwest, sometimes changing to a due east-west direction. This is the strike followed by the great Cracker Creek and Cable Cove system, by the Magnolia, the Greenhorn, the Alamo, the Susanville, and the Quartzburg veins. The prevailing dip is to the southeast or south, at angles from 45° to nearly 90°; but there are exceptions—thus, for instance, the strong and persistent Eagle vein, in Cable Cove, which dips toward the northwest at a steep angle. On the other hand, there are some districts with vein systems striking nearly north and south, or a few degrees east of this direction. Among them is the Cornucopia district, with veins dipping at moderate or steep angles east or west; the Pocahontas district, where flat westerly dips prevail, and the Red Boy, the veins of which dip from 50° to 80° W.

Still rarer is a northwesterly strike, usually coupled with a moderate southwest dip. Such veins are found in the Virtue district, at Connor Creek, Gold Ridge, and in the Bonanza district.

Regarded in a general way, the northeasterly or east-northeasterly strike of the veins is characteristic of the whole gold belt, and also coincides with its extension as a whole; just as much so, in fact, as the north-northwesterly strike is characteristic for the majority of the veins of the California gold belt.

It may not be amiss, in this connection, to call attention to a paragraph and a map in a previous report,[1] in which it is emphasized that

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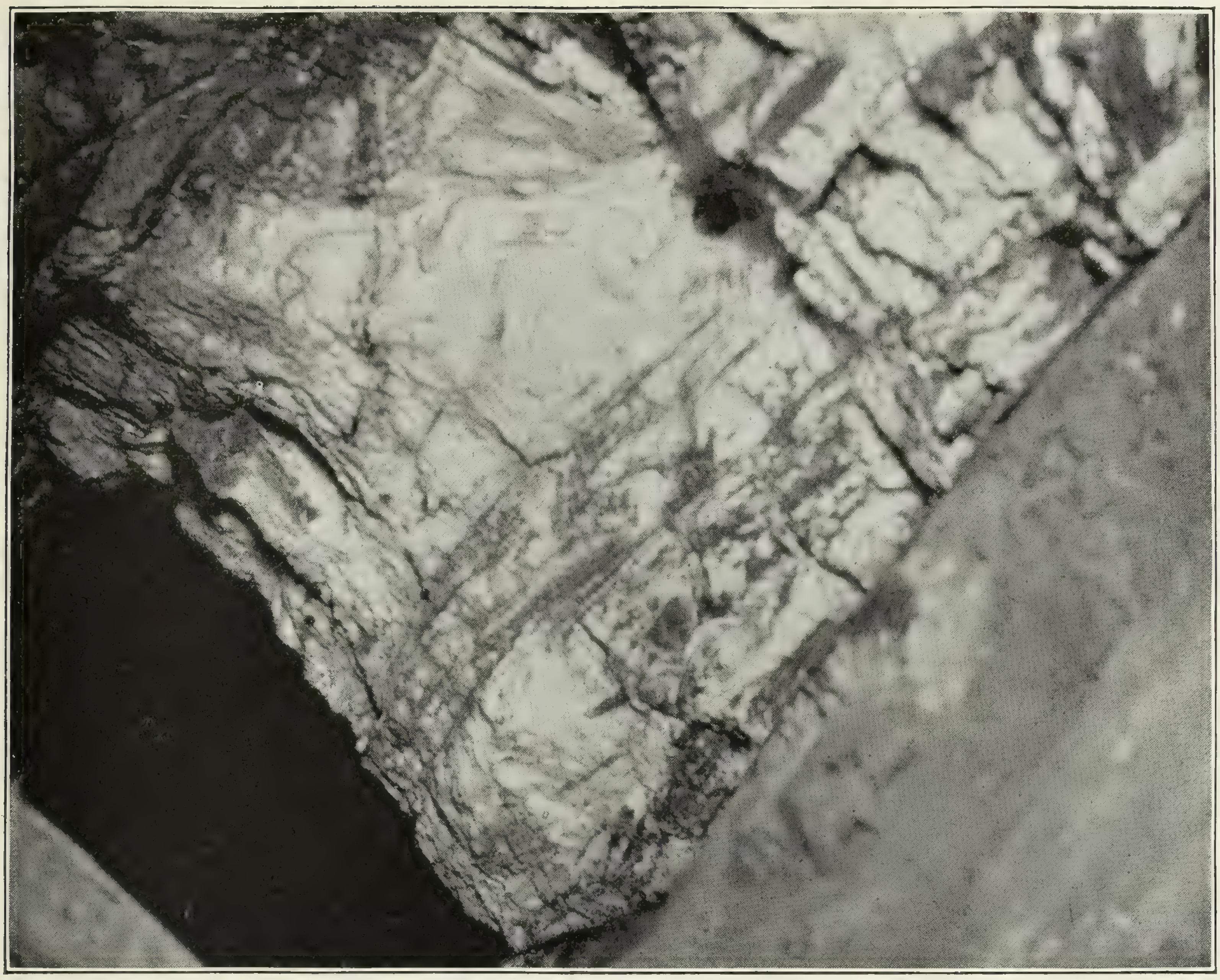
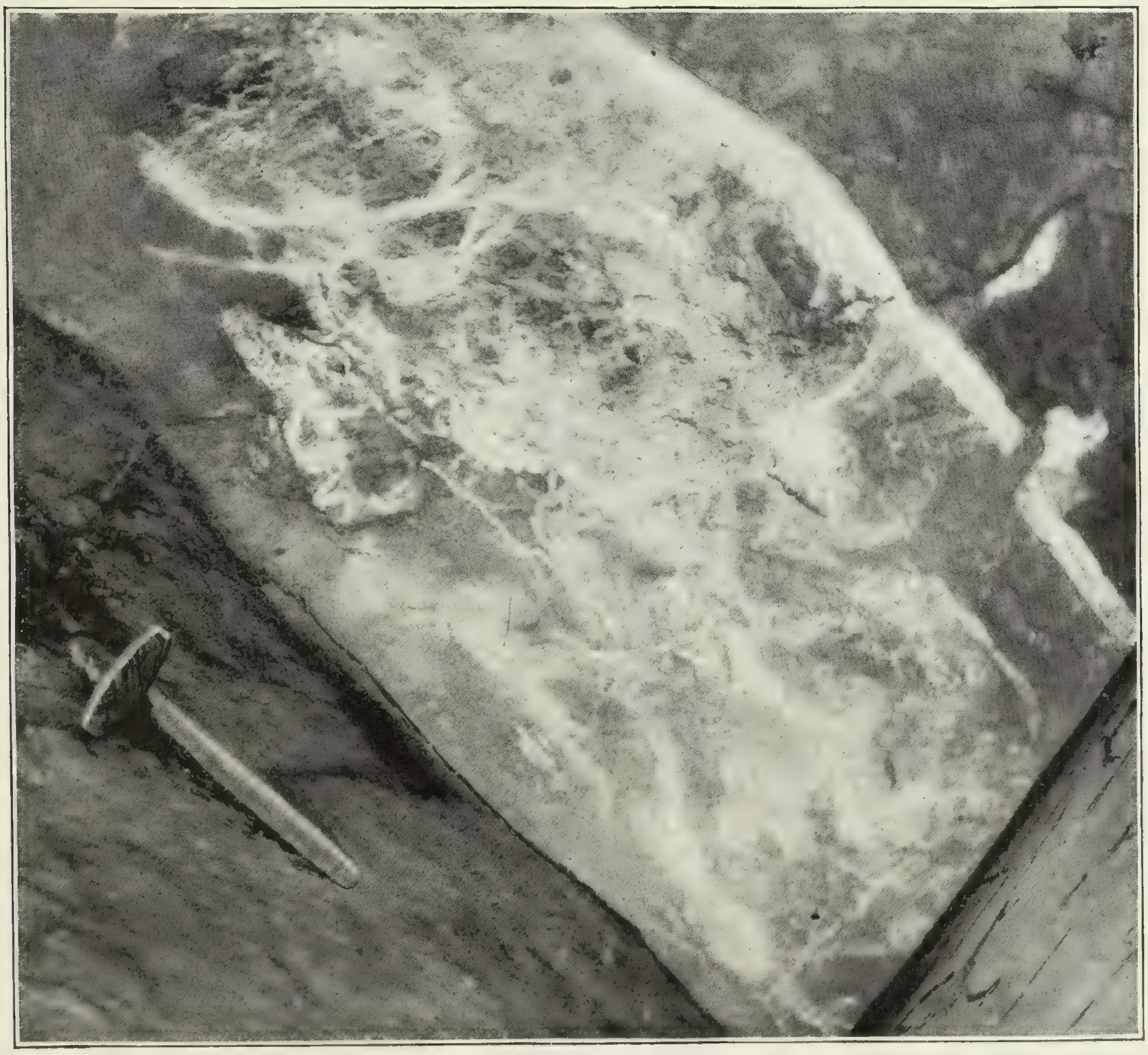
[1] The gold and silver veins of Silver City, De Lamar, and other mining districts in Idaho: Twentieth Ann. Rept. U. S. Geol. Survey, Part III, 1900, p. 101.



A. UNION-COMPANION VEIN.



B MONARCH VEIN.

the veins of central Idaho, with few exceptions, strike in a general east-west direction. Similar directions are found in parts of southern Montana adjacent to Idaho—as, for instance, at Butte; and it is now shown that the veins of eastern Oregon adhere to this rule, though it is not quite so exclusively maintained as in central Idaho. It was also pointed out in the above-mentioned report that this constancy in the strike of the fissure systems indicated that at the time they were formed the whole region constituted a solid crust block, which acted as a unit toward the disturbing forces. Nor is there in the Oregon district any evidence militating against the conclusion reached during the examinations of central Idaho that the fissures were formed under the influence of compressive stress acting in the main from north to south.

Wherever extensive vein systems were formed they have the character of linked veins—that is, the fissures are not absolutely continuous, but branches are thrown off at frequent intervals. The most important veins die out at some point and are replaced by other parallel fissures. A very excellent illustration is furnished by the vein system of Elkhorn, Cracker Creek, and Cable Cove, shown on the map. Beginning at the Baisley-Elkhorn with northeasterly strike, the veins continue across Rock Creek with east-west strike; on the divide between Rock Creek and Cracker Creek the direction again turns sharply northeast and the powerful North Pole vein begins. Continuing through the Columbia and the Golconda veins, the direction again gradually turns east-west, and the fissure gradually splits west of the Bunker Hill claim. But a short distance north of this point the exceptionally straight Ibex vein appears and continues without interruption for 2 or 3 miles. Again, parallel east-west veins appear a short distance north of Rock Creek and connect with the extensive fissure system of Cable Cove, which gradually swings around until near its westerly end it closely approaches the Ibex vein.

VEIN STRUCTURE.

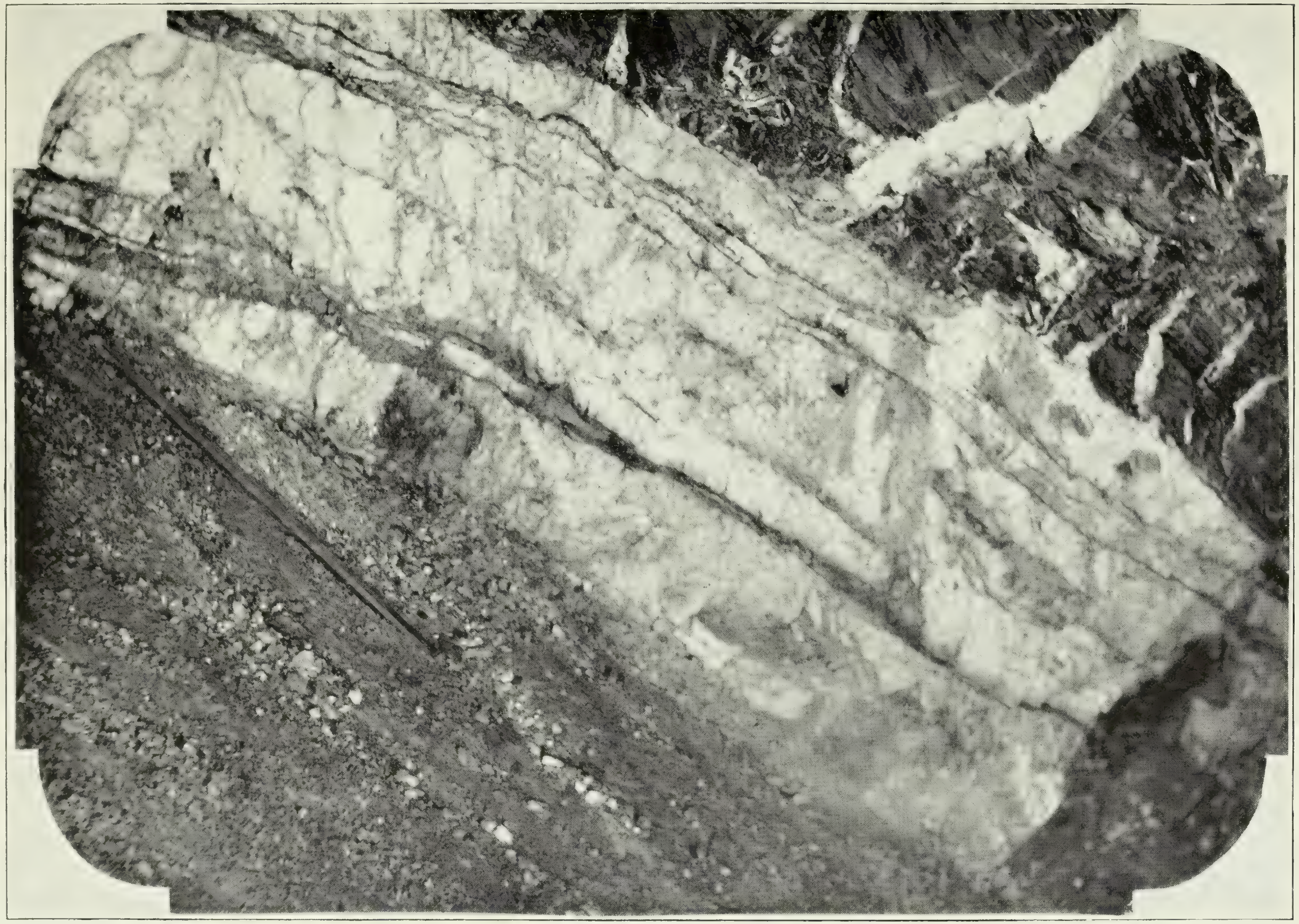
In regard to structure, several types may be distinguished among the fissure veins. The most common is that of the simple vein with a quartz filling, continuous over considerable spaces. The adjoining rock is rarely strongly sheeted by shear zones, and there are seldom parallel ore bodies in close contiguity. It is the simplest form of a gold-quartz vein, and is similar in type to many veins along the California gold belt. To this class belong the veins of Cornucopia, Sparta, Lower Burnt River, Pocahontas, Quartzburg, and many of the silver veins of the Greenhorn Mountains. It is illustrated by Pl. LXV, *A*, which shows a stope above the second level in the shaft of the Union-Companion vein, Cornucopia. It is an absolutely continuous filling of massive, coarse crystalline vein quartz with irregularly scattered sulphurets, 3 to 4 feet thick, between sharply defined and clear-cut walls of somewhat altered granodiorite. The assay value is about $20 per ton across the quartz. In both the upper and lower part the quartz is slightly sheared, as shown by the plate. For comparison a view of the Argonaut vein, Amador County, Cal., is represented in Pl. LXVI. This photograph was taken 650 feet below the surface, by Mr. O. H. Packer, a mining engineer of San Francisco. The vein is of massive quartz, containing some streaks of slate, as shown; it is in a country rock of clay slate and contains in the hanging many stringers of rich quartz; the vein itself is also good ore.

A second structural type occurs in regions of pronounced shear-zones, as, for instance, in the granodiorites of the Cable Cove district. The veins are here more closely spaced and there is more evidence of replacement. The sulphurets are more abundant, and parallel seams with new ore bodies may be found by cross cutting. The veins, however, maintain their individuality over fairly long distances. Some of the silver veins of the Greenhorn Mountains in diorite and granodiorite also show this tendency.

A third type is represented by the Cougar vein, which is a normal replacement vein. The values are contained entirely in the crushed argillite along a single fissure, and the quartz, if present, carries but little ore. The tourmaline-copper-gold vein of Copperopolis, in the Quartzburg district, is also practically a replacement vein, in which the diabase is irregularly altered into ore. On the whole this type is not common

A fourth type is developed in the pocket veins of Canyon. The fairly well-defined quartz veins of these deposits are poor or barren, while the seams accompanying them are filled with quartz or calcite rich in native gold.

The fifth type, and the most interesting, includes the gold and gold-silver veins in the argillite series. Among them are found the richest and strongest of the veins of eastern Oregon; they are chiefly developed in the Sumpter, Cracker Creek, Granite, Alamo, and Bonanza districts. Their peculiarities are due to the action of a strong, dislocating force on the brittle, siliceous argillites, so extensively developed in these districts. In their simplest type, as in the Monarch and Red Boy veins, they form strong and continuous fissures, with well-defined walls 2 to 5 feet apart. The vein filling is, however, not exclusively quartz, but a shattered mass of argillite, cemented by single veinlets or by a perfect network of veinlets with mineral quartz filling, often showing comb structure. Though altered and impregnated with pyrite, the slate does not often carry the pay, which is usually concentrated in the quartz seams. This type is illustrated in Pl. LXV, *B*, from a photograph taken in the Monarch vein, Red Boy mine, in a slope just above the tunnel level south of the crosscut.



ARGONAUT VEIN AT 650 FEET. JACKSON, AMADOR COUNTY, CAL.

In the Ibex and Bonanza veins the same type prevails, but the vein is wider, up to 40 feet, and of the composite type. There are sometimes several parallel walls and parallel masses of ore, consisting of shattered and recemented argillite. Frequent crosscutting is necessary; otherwise important ore bodies may escape attention. Most of the gold is contained in the quartz filling, but part of the ore also consists of a silicified argillite mud, which largely filled the fissures. Sometimes the breasts show a mass of argillite fragments embedded in massive quartz.

This type attains its extreme development in the North Pole vein, upon which some of the most celebrated mines of the Blue Mountains are located. It is a crushed zone, absolutely continuous for at least 4 miles and having a width of from a few feet up to 200 feet, averaging, perhaps, 25 feet. In very few places the walls approach each other within a few feet; no places were seen in which the fissure had locally closed down so as to contain no quartz. The normal developments show two well- or fairly well-defined walls, but no extensive system of parallel sheeting or shear planes. Between these walls lies a mass of quartz-argillite breccia; either of the constituents may locally prevail. Sometimes large bodies of pure, coarse, vein quartz appear, 10 feet to 20 feet in width, with only a few intermixed argillite fragments. Near the North Pole, Golconda, and the Bunker Hill mines enormous quartz croppings appear, measuring 100 and even 200 feet across. Very likely, however, this excessive thickness is deceptive and is caused in part by sliding or settling of the outcrops. At the Golconda mine the vein loses some of its distinctive features, and appears locally as a crushed zone, 200 feet wide, penetrated by irregular seams and veins.

FAULTS.

The veins of the Blue Mountains are very little affected by subsequent disturbances. Faults are not common and, when occurring, are of slight throw. In the Cornucopia district Neocene basalt dikes often cut and fault the veins, and similar conditions were observed in the Sparta district. Strong faulting movement has taken place in the Red Boy and in the Connor Creek mines. In the Cracker Creek and Cable Cove mines faults are not often encountered.

THE ORES.

The ores of these different classes of veins vary so much that they are best described under the types enumerated below. It may be said briefly that the predominating gangue is quartz, nearly always accompanied by a little calcite. More rarely the calcite or dolomite, the latter in serpentine areas, predominates. Accessory constituents are sericite, a chromium-mica (fuchsite?), and roscoelite. The latter two are found in several veins.

Among the ore minerals gold, more or less alloyed with silver, is of almost universal occurrence. The fineness varies from 930 to 500. The quantity amenable to plate amalgamation varies from a few up to 80 per cent. The sulphurets are those usually accompanying gold, viz, pyrite, arsenopyrite, zinc blende, galena, and chalcopyrite, the two latter rarely in large amounts. Arsenopyrite is very frequent, and, next to pyrite, the most common ore. Marcasite also occurs in the veins in argillite. Accessories are cinnabar, which is pretty common in the argillite veins, stibnite, tetrahedrite, mercurial tetrahedrite (schwatzite), pyrargyrite, and tellurides, the latter identified from the Cornucopia and the North Pole mines. A detailed list of minerals found in the area is given on pp. 642–643. The value of the ores milled at the mines ordinarily varies from $8 to $20, chiefly in gold; but considerable quantities of ore containing $40 per ton, or even much more, have been reduced in local mills. Concentrates and ores shipped to smelters vary from $30 to several hundred dollars per ton.

The silver veins carry in part the above-mentioned most common sulphurets; some of them carry also argentite, tetrahedrite, and pyrargyrite, but seldom much galena.

METASOMATIC PROCESSES.

The gold and silver veins contained in granodiorite, diorite, serpentine, and gabbro all show great similarity in the processes of alteration which the rocks have undergone close to the fissures. Excepted from this statement is the small group of tourmaline veins. The process consists in a metasomatic replacement of the ferromagnesian silicates, the feldspars, and to some extent also the quartz, by sericite, calcite, or allied carbonates and pyrite. In the Cornucopia mines and on the Gold Hill in the lower Burnt River district this alteration is particularly intense, but it is equally present in the Elkhorn district, in Cable Cove, and in the silver mines of Greenhorn Mountains. Locally the sericite or the calcite may predominate, and veins in serpentine and allied rocks present an exclusive alteration to dolomite. These abundant carbonates in the country rock stand in sharp contrast to the almost exclusively prevalent quartz filling of the veins.

The great similarity of ores and processes of alteration to the gold-quartz veins of California and of central Idaho, described elsewhere, is extremely striking and forms one of the most important generalizations to be drawn. The gold veins in the three States certainly owe their origin to extremely similar processes. The only difference between the California veins and those of eastern Oregon, as far as contents and alteration are concerned, is that the latter on the whole contain less free gold and more sulphurets than the former. Characteristic for both is the total absence of barite, fluorite, and tourmaline, as well as of garnet, ferromagnesian silicates, epidote, and iron oxides.

The interrelations of the vein systems prove almost conclusively that the veins in argillite are of the same age and of the same genesis as those in granular rocks, and yet in the more or less siliceous and carbonaceous argillite the metasomatic processes are of a different character. Extensive alteration has not ordinarily taken place, but very frequently the argillite is filled with sharply developed crystals of pyrite and also a little sericite. Where the alteration is intense a silicification has usually occurred, though the process is not widespread and does not affect any rocks outside of the walls, even in the largest veins. Some of the very richest shipping ore in the Columbia and the Golconda is probably a siliceous replacement of argillite.

In many veins two kinds of alteration appear; for instance, in the Badger mine, at Susanville; in the Golconda mine, at Sumpter, and the Connor Creek mine, on Snake River. Feldspathic rocks, whether sedimentary or igneous, are subjected to sericitization and carbonatization, while siliceous clay slates are silicified or impregnated with pyrite. The replacing solutions attack vigorously only the feldspars and the ferromagnesian silicates. Many argillites contain practically none of these minerals, but are composed of quartz and sericite, or quartz and kaolin, and on such minerals solutions of the kind here active are powerless as far as sericitization and carbonatization are concerned. But pyrite is formed, metasomatically, without difficulty, while the cryptocrystalline quartz is also recrystallized in larger and clearer individuals and additional quartz is deposited in every available space. In any rock with a large amount of quartz, mass action becomes a factor of importance when it is under the influence of this kind of solution, and more quartz will be deposited. The solutions contained much carbon dioxide, alkaline carbonates, and silica.

This course of alteration is entirely similar to that in the wall rocks of the California gold-quartz veins, though the reasons for the differences indicated were scarcely fully appreciated at the time the study of the latter deposits was undertaken.

PAY SHOOTS.

As in all gold-quartz mines, only certain parts of the veins contain gold-bearing material of sufficiently high grade to be considered as ore. It is recognized, of course, that the definition of ore is a fluctuating one, dependent upon the cost of mining and milling. Under the general conditions prevailing in eastern Oregon, this varies with the accessibility of the districts and the cost of reduction of the ores. Under favorable circumstances the cost of mining and milling can be estimated at \$3 to \$4 for free-milling ores, as well as for ores adapted for concentration, provided that a continuous ore shoot with a thickness of at least a couple of feet of ore is available. Theoretically, then, everything over $3 should be considered ore. As a matter of fact, the ores extracted run considerably higher, or at least $7 per ton. The mining and milling of ores of lower grade have not yet been extensively attempted, and when it is necessary to roast and cyanide or chlorinate the ore directly the expense must of necessity be much higher. In narrow veins with rich ore the expense of mining will also necessarily be higher, and in such districts distant from railroads merchantable ore must contain something like $25 per ton.

In most of the mines the development has scarcely progressed far enough to justify an opinion regarding the form of the ore shoots. Sometimes, indeed often, the ore bodies are very irregularly distributed, but in the majority of cases they are apt to form elongated bodies with a well-defined pitch in one direction or another on the plane of the vein. Ordinarily the pay shoots outcrop on the surface; this has been the usual case, many statements to the contrary notwithstanding. It was so in the Cornucopia, the Connor Creek, and the Virtue mines; also in Cable Cove, and in the North Pole, E. and E., and the Columbia mines. The Bonanza vein has been mined up to the grass roots, though the best ore was found only a couple of hundred feet lower. On the other hand, the Monarch pay shoot in the Red Boy mine did not reach the surface, though a few hundred feet below it has lengthened to 800 feet. The Red Boy vein had pay shoot only 100 feet long on the surface, which in depth attained a length of 800 feet. In the Golconda the croppings were very poor, and the ore body was revealed only after the shaft had been sunk. But this is exceptional. Extensive developments have often been undertaken below poor croppings without successful results. The conclusion is that, while good mines may be developed from poor croppings, the chances are against it, here in Oregon as elsewhere, where gold-quartz veins are concerned. The reason, however, why the barren croppings are so much more conspicuous than the rich is that the latter, being usually less compact and more easily oxidized, are very often eroded and covered by soil and detritus.

The quartz between the pay shoots is sometimes entirely barren, but is more apt to contain from a trace to $2 or $3 in gold. In some smaller veins pay appears wherever quartz filling has had an opportunity to form.

In the Union-Companion mine, Cornucopia, the ore shoot, as far as proved, pitches south on a vein dipping west. In the Virtue mine somewhat complete data are available, and the pay shoot has approximately the form shown in fig. 86. It will be noted that on the surface the shoot was only 200 feet long, but that below the first few levels it rapidly widened to 1,200 feet, a width maintained to a depth of 1,100 feet below the surface. On level No. 7 the vein became impoverished and very little pay was found; on No. 8, though, the vein continued without break. No very decided pitch was noted in the continuous, almost rectangular shoot, which comprises an area of 960,000 square feet. The average thickness was 14 inches, whence followed an average yield per square foot of the plane of the vein of $2.29, or a value per ton of $24.23, the total output being $2,200,000. This is more than the average value of the lower and larger part of the shoot, which was $16 per ton. From this it may be concluded that the value of the ore near the surface was considerably higher than the average in depth. (See below, under the heading "Secondary enrichment.") From the developments on levels No. 7 and 8 it was concluded that the pay shoot was exhausted, and the mine was considered worked out and allowed to fill with water. If the vein, as is stated, really continued unbroken on these levels it may be questioned whether this is a safe conclusion. Barren stretches for 200 feet in depth, or even more, are by no means unknown among gold-quartz veins, and without further and deeper exploration it would be rash to say that the ore deposition really had ceased at a depth of 1,000 feet from the surface.

In the great North Pole vein, in Cracker Creek district, are at least three pay shoots separated by wide spaces of poor quartz (fig. 81). The first is that of the North Pole, continued in the E. and E. mine. It is several hundred feet long measured along the levels, and pitches 20°–30° SW., the vein dipping 70° SE. It has been followed for 2,500 feet along its pitch. Fifteen hundred feet farther southwest is the Columbia shoot, also several hundred feet long, having the same pitch and having thus far been followed for 2,000 feet along this pitch. Two thousand feet farther southwest is the Golconda ore shoot, which has a more irregular outline, and thus far shows no decided pitch. The beginning of another ore shoot has been found northeast of the North Pole and E. and E. shoot in the workings of the former vein.

On the Ibex vein, continuous for 3 miles, a great number of pay shoots have been found, which, however, are usually of less extent along the strike of the vein than those of the North Pole vein, and which also, as a rule, are more irregular and show rapid variations in their tenor. In a distance of 4,500 feet in the Ibex and Bald Mountain mines at least six shoots occur, which, like those of the North Pole vein, pitch southwest on the vein, the latter having a steep southerly dip. The maximum length along the drift is 200 feet; the pitch is much steeper than in the North Pole vein.

An interesting observation is the general coincidence of the pay shoots on the parallel and adjoining Monarch and Red Boy veins in the Red Boy mine. Even the richest placers in the two veins appear to be opposite each other.

The next subject to be considered is the width of the shoots in the composite veins. In the simple veins the whole width of the quartz, or, in veins poor in quartz, the whole width of the sulphurets, ordinarily constitutes pay ore. A difference is sometimes found, as, for instance, in the Monarch vein (Pl. LXV, *B*), in which the 2 feet next to the foot wall contain the best ore. The whole width is, however, milled. Other instances of similar relations are not wanting. In the Baisley-Elkhorn mine, for instance, a 2-foot-wide body of rich sulphide ore was in one place adjoined by 2 feet of nearly barren quartz. In wide veins in granodiorite, like the Eagle vein in Cable Cove, which consists of 15 feet of crushed rock between well-defined walls, this width contains one or more pay streaks of sulphurets from a fraction of a foot to several feet wide. The pay streaks change from foot wall to hanging wall and occasionally overlap; but wherever there are sulphurets there is also pay.

In the pay shoots of wide, composite veins in argillite other and more complicated conditions prevail. Out of a total width of quartz and quartz-argillite breccia of from 7 to 40 feet, or even more, the pay is usually confined to a streak from 1 to 4 feet in width. This streak may lie on either wall and sometimes crosses diagonally from one wall to another, or it may break up into several stringers of pay ore. The pay streak is often adjoined on both sides by normal quartz, sometimes differing but little in appearance from the ore. Ordinarily, however, to the practiced eye there is a difference, consisting in a looser or more crumbling condition, or in the occurrence of finely distributed pyrite and arsenopyrite in the ore. This suggests at once that the pay streaks may be secondary breaks and fissures enriched by concentration from a great width of lean ore. This should not be understood as meaning concentration under the influence of oxidizing waters or a concentration in any way dependent on surface conditions. If these streaks really are secondary enrichments, they have been effected under the influence of the same kind of solutions that formed the vein as a whole, and may be relied upon to continue in depth. But the question is by no means simple, and much more extended observations than those which could be made on a rapid reconnaissance are necessary to settle the question. In some cases there seems to be no difference in the character of the quartz outside and inside of the pay streaks except in the content of gold in the latter. On the other hand, it is often found, as, for instance, in the North Pole vein, that extensive crushing and brecciating has taken place in the pay streaks and the fragments are recemented by calcite and secondary sulphurets. The cemented fragments are not barren quartz but contain arsenopyrite in unquestionable primary deposition. The argument for secondary concentration is further weakened by the fact that in many places the barren quartz shows a similar brecciation and calcitic cement. The difficulty is to account for deposition of ore in certain streaks which occasionally cross the vein, while the whole space was filled with metalliferous solutions and deposition of quartz went on throughout. The theory of a secondary concentration is very attractive, but the occurrence of well-defined and parallel pitching ore shoots on the plane of the vein remains to be explained as well on this supposition as on the theory of their direct formation from original deposition.

In some veins, like the Bonanza, and on the Belle of Baker claim, on the Ibex vein, large bodies of high-grade quartz and breccia of quartz and country rock occur with a width up to 40 feet, while parallel and closely adjoining fissures may carry very low-grade quartz. Again, there are some veins in argillite which in a width of 10 to 20 feet carry approximately even values of from $3 to $5 per ton.

Within the great ore shoots it is not uncommon to find smaller bodies of extremely rich ore. Pockets of gold and argentite occur in the Connor Creek mine and similar bunches of coarse, high-grade gold in the Virtue mine. Similar bodies are found in the North Pole, E. and E., Columbia, and Golconda mines, here containing pyrite, chalcopyrite, tetrahedrite, native gold, and sometimes telluride in a gangue of quartz and roscoelite. These rich pockets are small and irregular masses or narrow chimneys. An unusually large mass of this kind in the Golconda mine was 70 feet long and 14 feet wide and pitched flat in a southeasterly direction across the general trend of the vein, which is here a broad, crushed argillite zone with quartz stringers rather than a well-defined fissure. Most cases of this kind are not, I believe, due to a secondary concentration, but bear the ear marks of original deposition.

In conclusion, there is no uniform law as to the form and the pitch of the shoots. In the Nevada City and Grass Valley districts of California it has been shown that the shoots usually pitch to the left of the observer, standing on the croppings and facing in the direction of the dip of the vein. While this corresponds to the general observations in the Cornucopia district, the rule is reversed in the North Pole and in the Ibex veins.

The satisfactory explanation of the ore shoots is one of the most difficult parts of the study of ore deposits. None of the ordinarily advanced theories is entirely satisfactory. Prof. C. R. Van Hise, in a recent paper,[1] believes, in common with some other geologists, that the cause is to be sought in cross fractures carrying different solutions from those found in the main fissure. The ore is precipitated by the reaction of these differing solutions. It can not be said that much evidence has been found in this region to support this view. The only place where cross fractures seem to have any influence upon the ore at all is in the Cable Cove district (see detailed description), and here they locally interrupt the continuance of the ore rather than favor it.

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[1] Some principles controlling ore deposition: Trans. Am. Inst. Min. Eng., Vol. XXX, 1901, pp. 27-177.

DEPTH ATTAINED AND THE QUESTION OF PERMANENCY.

The quartz-mining industry in the Blue Mountains is of comparatively recent date, and hence for the most part the mines have not as yet attained great depth. The Connor Creek mine, on Snake River, has reached a depth of 1,000 feet from the croppings, developed by tunnels. Rich ore has recently been found on the lowest level, though the ore shoot is not developed in full force as far as the present explorations go. The Virtue mine is 1,100 feet below the croppings, developed by an 800-foot vertical shaft. The ore shoot, continuous from the surface to a depth of 900 or 1,000 feet, was found to be too poor for working on the deepest level. While the ore in depth was poorer than the oxidized portion, I do not understand that a gradual decrease in the tenor took place. The Cornucopia mines have been worked 500 feet below the croppings with continuous ore shoots. The North Pole has been opened by tunnels to 1,000 feet or more below the croppings; the Columbia by a 500-foot shaft to a point 1,000 feet below the highest croppings on the same claim. The total vertical distance between the highest workings in the North Pole mine and the lowest in the Columbia mine is at least 1,700 feet, and on the deepest levels the ore continues of the same grade as nearer the surface, from the lower edge of the zone of oxidation. The Bonanza mine is opened by tunnels and shaft to a depth of 450 feet below the croppings, good ore being found in the lowest levels.

Regarding the permanency of the veins, there are very good reasons for believing that the strong, well-defined veins upon which most of the important mines are located will continue to the greatest depths yet attained in gold mining. Judging from analogy with other regions, it is also probable that the pay shoots will continue in depth, though the unbroken continuation of one and the same ore shoot should not be relied upon with confidence. It has been the experience of most deep gold-mining enterprises that barren levels will occasionally interrupt the richest and most extensive ore shoots. Smaller fissure veins, members of a great number of veins in close contiguity and which have no great length, are not to be relied upon with as much certainty. But, taken as a whole, the strength of the vein systems and the mineralizing action are important factors in favor of the future of this mining region.

SURFACE OXIDATION.

In eastern Oregon, as in most mining regions, the portion of the veins adjacent to the surface has undergone certain changes, due to the action of oxidizing waters. In late years much attention has been devoted to these phenomena, and the studies of Messrs. Emmons, Weed, and Van Hise have placed the active processes in a much clearer light. Their importance to the mining industry can not be overestimated, for the future value of a mine depends greatly on the extent of the secondary surface processes and of their certain identification.

In a broad way, the processes of oxidation and the sulphide enrichment accompanying them in greater depths are more active and extensive in an arid climate than in a region of heavy rainfall, where the water level stands high. The Blue Mountain region is essentially one of great precipitation, and has in all probability been so since Neocene time. It is further true, in a general way, that gold-quartz veins are less readily affected than silver and copper veins, due, no doubt, to the more difficult solubility of the gold. Furthermore, some of the districts in this region are located in areas of former glaciation, which has swept away the softer products of oxidation, the limonite and the cellular quartz of the "iron cap."

The general conclusion, then, is that secondary surface enrichment has played a comparatively unimportant part in this region. It is, however, undoubtedly present, as shown by the following examples selected from the detailed descriptions:

From Pedro Mountain near Rye Valley, from La Belleview and the Monumental mines in the Granite district, and from some parts of the Greenhorn Mountains come reports of extraordinarily rich silver ore in the croppings immediately below which poorer ore was found. This is in line with what is known about silver veins elsewhere, and may without doubt be attributed to surface enrichment.

Among the gold veins with coarse sulphides and no free gold the surface, down to 25 or 50 feet, is generally reported to contain limonite with free gold and richer ore than below. Those at Cable Cove and Susanville are examples of this.

Among the gold-quartz veins with much free gold the upper parts of the vein, from the surface to a depth of from 100 to 300 feet, are generally more or less oxidized and richer than the unaltered ore below. At the Sanger mine, on Eagle Creek, the uppermost 100 feet showed a narrow vein yielding $25 per ton, while below the vein widened and the average values were reduced to $12 per ton. At the Virtue mine the upper two or three levels yielded $25 per ton, while the main part of the ore shoot averaged only $16 per ton. Although in a locally arid district, deeper oxidation is excluded in this case, for below the first few levels the mine contained an abundance of warm water, in all probability under ascending pressure.

In the gold veins in argillite of the Cracker Creek and Granite districts the sulphides are generally in very fine distribution and the ore is often quite hard. In connection with a high permanent water level this results in an oxidized zone which, on the steep hillsides of the North Pole claim, extends 200 to 250 feet from the surface. The ore in this zone is only partly oxidized, and the difference in tenor between it and the deep unaltered ore is surprisingly slight. Average assays of surface ore give 0.968 ounce gold and 0.700 ounce silver per ton, a total of $20.40 per ton. In the fresh ore is very little free gold; in the oxidized ore a little more, but enough is not set free to convert the substance into free milling ore, so that a preliminary roasting is necessary for purposes of the cyanide process. If no great change of volume has taken place during the process, the weathering has had the effect of slightly increasing the gold and decreasing the silver.

The Ibex vein, situated in the glaciated area, shows little evidence of surface decomposition. I believe that the bodies of rich ore, 40 feet wide, found in the Belle of Baker near the surface, as well as in the Bonanza vein 300 feet from the surface, are due to primary deposition, and have not been enriched by oxidizing action.

No decided evidence of sulphide enrichment due to surface waters has been found. The ores should be expected to continue for great depth below the relatively shallow zone of oxidation without notable change in character and tenor.

AGE OF THE GOLD AND SILVER VEINS.

The gold and silver veins of the Blue Mountains with few exceptions consist of a number of very closely related structural and mineralogical types. It is difficult to avoid the conclusion that they are all of about the same age. They occur in argillite, granites, granodiorites, diorites, gabbros, and serpentines. They cut Triassic sediments in the Eagle Creek Mountains; they cut older argillites which with reasonable certainty may be assigned to the Paleozoic age; finally, they never appear in the Neocene basaltic, andesitic, and rhyolitic lavas. The conclusion is that they are post-Triassic and pre-Neocene. The California gold-quartz veins are post-Jurassic and pre-Neocene; we may even fix their age a little closer, for they are doubtless also earlier than the Chico Cretaceous. The vein systems of central Idaho are determined as post-Carboniferous and pre-Neocene. It is very probable that the veins in the three regions date from about the same period, i. e., the early Cretaceous.

A strong mineralization of the Neocene lavas has been noted in Owyhee County, in southern Idaho. The only instance in this region of a post-Neocene mineralization is in the case of a dike of rhyolite 9 miles south of Prairie, which undoubtedly contains traces of gold and silver.

INFLUENCE OF COUNTRY ROCK.

It has been stated that the gold and silver veins appear in almost all of the different rocks of the region, excepting the Neocene lavas; the influence of the country rock upon the character of the ore is next to be discussed. When smaller districts are examined differences due to the varying character of the country rock may be distinguished; but to a great extent these are effaced when the region as a whole is considered. Most of the big-producing mines are in slate or siliceous argillite; for instance, the Bonanza, Red Boy, North Pole, Columbia, Golconda, and Connor Creek mines; but, on the other hand, the Virtue is in tuffaceous greenstone, and the Baisley-Elkhorn and the Cornucopia mines in diorite or granodiorite. It may perhaps be said that in granite or diorite there is apt to be less free gold and a greater percentage of sulphurets, but this is a doubtful rule, for some of the greatest mines in argillite, like the North Pole and E. and E., contain very little free gold and abundant sulphurets. The same is true of the Badger mine at Susanville. Veins in serpentine are usually narrow and short, with much dolomite gangue and coarse, pure gold.

It would seem that here, as in California, the influence of locality overshadows that of the country rock entirely. That is, if gold-bearing veins are developed at any place, they are likely to be found in any of the various rocks which appear at that place.

No doubt the difference in the character of the fracture in argillite and in granitic rocks greatly influences the deposition. A wide fracture zone is apt to contain a different ore from narrow fissures through which the solutions found their way with difficulty; and the fact that granitic and dioritic rocks are altered in a different way and more easily than the siliceous argillite can hardly fail to make the character of the solutions circulating in the open spaces somewhat different in the two cases. This may account for a relative abundance of sulphides in the granular rocks and a less amount of free gold in them.

VARIATIONS OF THE PAY SHOOTS.

It is an interesting fact that adjoining pay shoots in one and the same vein may differ considerably in the character of the ore. This applies particularly to the North Pole and Ibex veins. The North Pole and E. and E. ore shoots on the North Pole vein contain very little free gold; the sulphurets are of high grade. The Columbia ore shoot contains more free gold and also more silver than the former. The Golconda contains free gold, but the sulphurets are poorer than in the Columbia. These data refer, of course, to the fresh, unoxidized ore. In the Ibex mine three pay shoots show successive variation of the relative proportion of gold and silver. The first shoot contains 90 per cent gold and 10 per cent silver, the last 40 per cent gold and 60 per cent silver.

GEOLOGICAL RELATIONS OF THE VEINS.

While at first glance the veins seem to be scattered irregularly in respect to geological areas, a closer inspection reveals some interesting relations.

Relatively few deposits are contained in the great area of granodiorite of the northern Elkhorn Range, the extensive area of sedimentary rocks of the Eagle Creek Range, or the area of argillites on both sides of the Burnt River Canyon above Durkee.

On the other hand, the veins certainly appear massed near the contacts of sedimentary rocks with granular intrusive rocks. Most conspicuously does this show in the great Elkhorn-Cracker Creek-Cable Cove vein system, which accompanies the contact for many miles—not closely, indeed, for none of the veins follow the actual contact. The veins are now in diorite or granodiorite, now in argillite, continually branching, crossing the contact, and throwing out divergent systems several miles either way from the contact. Near Granite another vein system is developed, crossing the contact. Near the Red Boy, Alamo, and Greenhorn districts another intrusive area of granodiorites, diorite, gabbro, and serpentine begins, and new vein systems appear in them or in the argillites broken by their intrusion. At Bonanza serpentine accompanies the argillite, as it also does at Susanville. At Canyon serpentine and diabase adjoin slate areas. In the southern Elkhorn Range dioritic rocks have shattered the sedimentary series. In the Virtue mining district the veins occur on both sides of a contact between diorites and gabbros and argillite. In the Cornucopia mining district rich veins appear at the intrusive contacts of granodiorite and schists; at Sparta in granite adjoining sedimentary rocks. Finally, the local gold belt of the lower Burnt River, extending from Connor Creek to Malheur, a distance of 30 miles, follows three intrusive areas of diorite and granodiorite—those of Lookout Mountain, Pedro Mountain, and Amelia.

These relations are too evident to be overlooked. It seems certain that the occurrence of rich gold and silver veins in this region is, in some way, connected with the occurrence of intrusive rocks, which more rarely are granites, more commonly granodiorites, diorites, gabbros, or serpentines. This by no means implies that all the veins, nor even a majority of them, are contained in these intrusive rocks. They are just as apt to be found in the sedimentary areas in the vicinity of the intrusive masses. This conclusion is important, as similar evidence has been gathered from so many other regions of auriferous veins.

To fully appreciate this connection and to reach the safe conclusion to be drawn from the facts, a careful comparative study of the auriferous regions of the world must be undertaken. This can not be done at this place, and the probable genesis of these deposits will, therefore, be merely indicated in a few words.

GENESIS OF THE VEINS.

The veins of the Blue Mountains were formed at a relatively remote period, and few traces of the active agents of their formation can be found now. From data concerning the character of the filling, it is here, as in the case of almost all gold-quartz veins, perfectly safe to conclude that the mode of deposition has been exclusively aqueous. From the fact that they occupy important systems of fractures which doubtless continue in depth to a distance commensurate with their extension in length, and from the fact that as far as followed they exhibit no notable change in the character of their filling, we may feel confident that the fissures were channels conveying currents of ascending waters. Wherever these solutions came in contact with rocks capable of metasomatic alteration, a strong action is noticeable on the latter, most intense nearest to the fissure and gradually fading away at a distance. From the further fact that by this alteration silicates are entirely converted to carbonates and sericite, we conclude that the waters contained a strong percentage of carbon dioxide and alkaline carbonates. All these facts point strongly toward thermal waters, hot ascending currents, as the chief factor in the deposition. Much of the gangue was doubtless extracted from the immediately surrounding country rock. Confirming this is the prevalence of dolomitic gangue in veins in serpentine; but the zone from which this material has been extracted is too limited to make it probable that the gold and silver were extracted from the country rock. Militating against this is also the fact that similar veins are found in most widely differing rocks. It is more probable, perhaps, that the thermal waters obtained their heavy metals from gaseous emanations along the contact of magmas cooling at great depth.

The comparison between the copper deposits and the gold-silver veins, which will be found at the end of the discussion of the former, is most interesting. Conceding aqueous deposition for both classes of deposit, the metasomatic processes and the general structural relations are very different, indicating for the gold deposits a deep-seated origin and for the copper deposits a genesis more closely connected with surface phenomena.

MINERAL CLASSIFICATION OF PRIMARY GOLD AND SILVER VEINS.

GOLD VEINS.

Virtue type.—These are simple fissure veins, with quartz filling, in sedimentary, and, more rarely, in igneous rocks. The ore consists principally of native free-milling gold, often coarse, and always very pure, ranging from 850 to 950 in fineness. The highest grade of gold is found in the Virtue and Connor Creek mines. A very small amount of arsenopyrite, pyrite, and more rarely other sulphurets is present. Occasionally, also, small amounts of tetrahedrite, argentite, and stibnite are found. Besides quartz, a little calcite and occasionally white massive scheelite (Flagstaff, Cliff) occur as gangue. The value is exclusively contained in the quartz filling, scarcely ever in the altered rock. In slates the alteration is confined to pyritization and occasionally a little carbonatization. In granular rocks there is strong carbonatization with the development of pyrite and a little sericite. Examples are the Virtue, White Swan, Flagstaff, Pocahontas, and Connor Creek mines; probably also the Sanger mines. Specimens from the Connor Creek mine show normal white vein quartz of coarse texture and partly idiomorphic outlines of the grains. It is filled with irregular inclusions and contains, crystallized together with the quartz, coarse idiomorphic arsenopyrite, with which the gold is associated; the latter, of deep-yellow color, either surrounds the arsenopyrite or occurs in intimate intergrowth with it. Most of it is coarse, though it also occurs as fine dust and films through the arsenopyrite. It is observed wholly included in the coarser quartz grains, but also along the contacts of the grains, as if deposited by a secondary migration. Wherever the quartz shows parallel partings or ribbon structure in the specimen evidences of pressure are observed in the sections. The large quartz grains throughout the slides are optically disturbed, and along lines coincident with the "ribbons" extensive crushing appears, with the formation of new quartz aggregates and veinlets of calcite, a mineral which sometimes also occurs in larger grains mixed with the quartz. Along these secondary fractures cubical pyrite has recrystallized and threads of gold are also observed, probably a mechanical deformation of the primary deposit.

The clay slate adjoining the vein is a microcrystalline mosaic of quartz, probably also feldspar, traversed by curved and contorted streaks of carbonaceous matter. It contains cubical pyrite as well as seams of calcite and quartz; calcite also in part replaces the slate.

An extremely altered narrow dike follows the Connor Creek vein throughout. Its structure is porphyritic and its groundmass microcrystalline, consisting of quartz and feldspar. Beyond that it can not be identified. The grayish soft rock contains about 20 per cent each of sericite and calcite, together with a few sharply defined crystals of pyrite. It is cut by a few normal quartz seams.

The quartz of the Virtue mine is similar to that from the Connor Creek, though arsenopyrite is generally absent. The wall rock is a soft, very altered greenstone, probably an old volcanic tuff. The rock is filled with seams of calcite, which also largely replace the rock. The remaining feldspars contain a little very minutely divided sericite. Pyrite and some pyrrhotite are also among the metasomatic developments.

The quartz of the Flagstaff mine is again similar, but contains some grains of brownish calcite intergrown with the primary quartz. This calcite again incloses small prisms of quartz.

Canyon and Robinsonville types.—These two divisions also contain coarse free gold of high grade, associated with some sulphurets, but they differ somewhat from the Virtue type. Apparently without exception they are contained in serpentine, gabbro, diabase or diabase-porphyry, and rarely have great length or width. The ore usually occurs in rich pockets.

In the Canyon type well-defined, almost barren quartz veins in gabbro or diabase-porphyry are accompanied by complicated systems of seams. Coarse gold is found in rich pockets in these seams and has a tendency to crystalline development. The gold occurs in quartz or in calcite. When in the latter it seems to be later than that mineral and its introduction is accompanied by a shattering of the coarse calcite and a simultaneous deposition of a little quartz (Pl. LXIX, *C*).

The country rock is greatly carbonatized and also contains metasomatic pyrite. The development of the latter along minute fissures and its characteristic calcite rim is illustrated in Pl. LXX, *B*. Sulphurets other than pyrite are generally absent. Veins of the Robinsonville type are also chiefly pockets, but the gold is more confined within the vein and the development shows greater variation. The vein filling is quartz of normal, coarse granular type; the crystals are sometimes (Pl. LXX, *A*) cemented by chalcedony. In serpentine, however, as in the Junebug and Don Juan veins, the gangue is chiefly of dolomite, no doubt derived from the country rock. Both dolomite and quartz contain coarse gold. Among the sulphurets, galena, remarkably enough, often predominates and is directly associated with the gold, but chalcopyrite is also present (Banzett, Diadem). The alteration of the country rock is usually a carbonatization, dolomite being frequently formed.

Cornucopia type.—These are normal, simple quartz-filled fissure veins, containing free gold of a fineness from 870 down to 700. The sulphurets, of which from 5 to 10 per cent is present, are usually rich in gold and sometimes also contain some silver. They consist of pyrite and arsenopyrite, with a little zinc blende, galena, and chalcopyrite. Tellurides are sometimes present. The ores are free milling to the extent of from 30 to 60 per cent. These veins show great similarity to certain California types. The country rock is usually a granodiorite, diorite, or diabase, and is strongly altered to a white, soft substance containing very abundantly calcite, sericite, and pyrite. Examples of this type are found at Cornucopia, Sparta, Gold Hill, and Gold Ridge (Burnt River). It is very similar to the Gold Hill type described from central Idaho.[1]

The quartz from Cornucopia is a normal, coarse vein quartz, greatly crushed and showing optical anomalies in thin section along lines where the ribbon structure appears in specimens. Abundant irregular aqueous inclusions are massed along certain lines. Intergrown with this quartz are pyrite, chalcopyrite, and a colorless zinc blende. Secondary calcite has been introduced along irregular cracks.

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[1] Twentieth Ann. Rept. U. S. Geol. Survey, Part III, 1900, p. 105.

The quartz from the Present Need mine, Quartzburg, shows normal coarse structure and is full of large irregular aqueous fluid inclusions with large bubbles. Between the grains lie anhedrons of pyrite, chalcopyrite, galena, and grayish-yellow marcasite. The pyrite and marcasite are intimately intergrown with native gold.

Cable Cove type.—In this type the sulphurets predominate, and the free gold makes up only a small part of the total value. When it occurs, the free gold is of a low value, from 650 to 750 fine. Among the sulphurets pyrite and arsenopyrite predominate, but zinc blende, galena, and chalcopyrite also occur. Rich silver ores are not uncommon (tetrahedrite and pyrargyrite), and altogether there is more silver than in any of the preceding types. Cinnabar is abundant in the placer mines of Susanville, and may have been derived from veins of this type occurring near by. The gangue, which is not very abundant, consists of quartz, but there is also considerable calcite present.

The alteration of the country rock, when of granodiorite or diorite, shows the normal sericitization and carbonatization. When the country rock is slate the veins are accompanied by local and slight silification. A part of the ore is probably formed by replacement of the country rock. Representatives of this type are the Cable Cove mines, the Baisley-Elkhorn, and the Badger mines, at Susanville. This type is somewhat similar to the Willow Creek type from central Idaho.[1]

At the Baisley-Elkhorn the free gold, which amounts to 25 per cent of the total value of the ore, sometimes occurs as wires in a black zinc blende, very intimately intergrown with calcite and a few grains of quartz.

The diorite from the same locality is greatly altered close to the vein. The feldspars are almost completely converted into sericite and calcite, the latter characteristically filling the spaces between the sericite foils. Cubes of pyrite develop in this mass and in the quartz, which otherwise is but little altered. The biotite is partly altered to chlorite, but chiefly to muscovite foils.

In the Cable Cove veins there is less free gold. The vein quartz, when present, is of the normal, coarsely crystalline type (LXIX, *A*), containing well-defined crystals of arsenopyrite and other sulphurets. In a few places a little chalcedony may be noted between the quartz grains. The aqueous inclusions are abundant, but small and irregular, mostly with large stationary bubbles. The granodiorite next to the ore is normally altered to sericite with a little calcite. Fairly pure galena from the Imperial contained 0.74 ounce gold and 60.86 ounces silver per ton, while the pure arsenopyrite from the same mine assayed 5.82 ounces gold and 7.08 ounces silver per ton.

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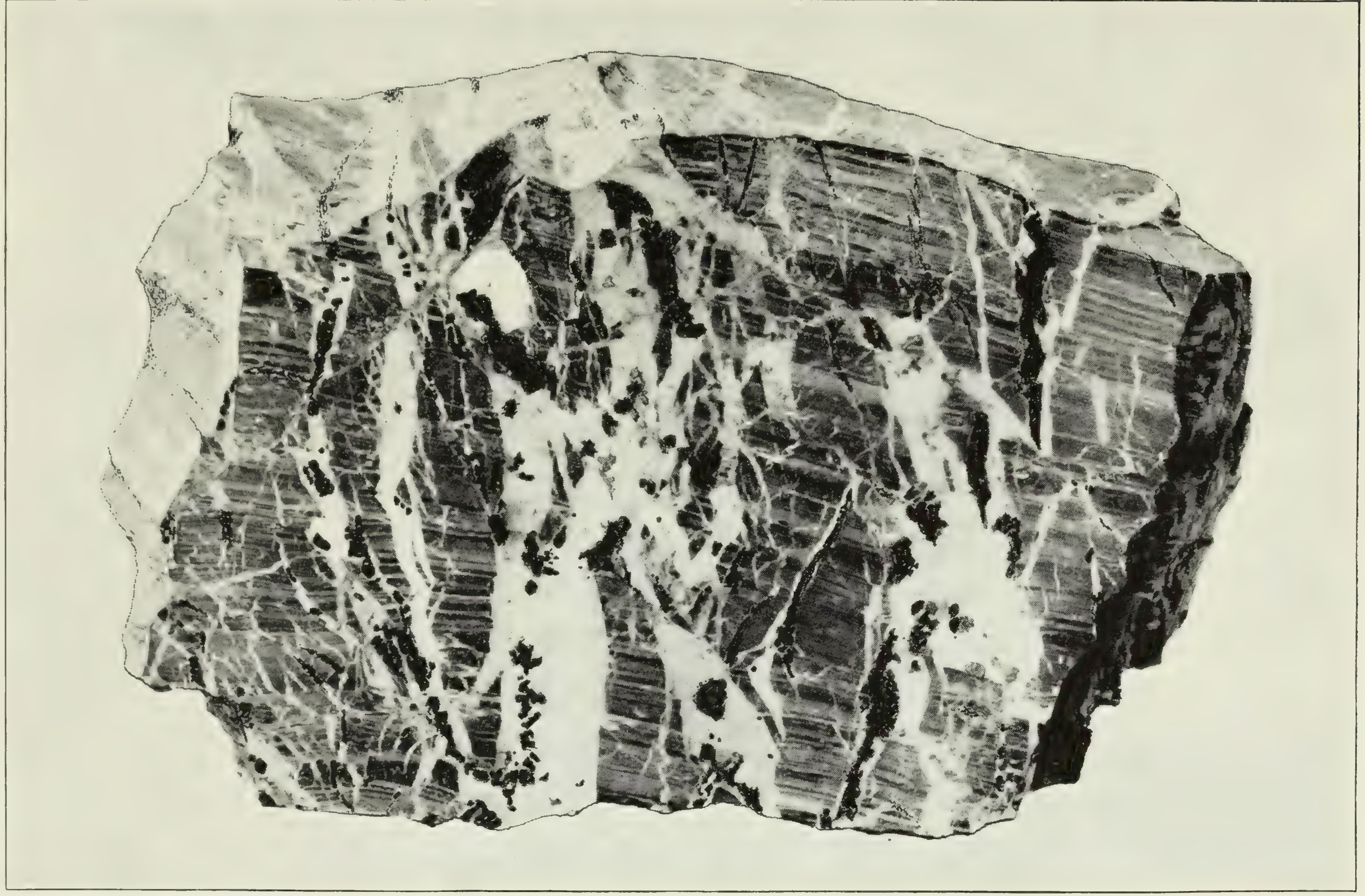
[1] Lindgren, loc. cit.



SPECIMEN OF GOLD ORE, BADGER MINE.

At the Badger mine the coarse pyrite and arsenopyrite is of lower grade, while finer mixtures of these minerals with a little galena, zinc blende, and tetrahedrite contained 1.04 ounces gold and 909.08 ounces silver per ton. The country rock at the Badger mine is a clay slate, developed in at least two modifications. The metasomatic alteration differs correspondingly in an interesting manner. The first is a black, somewhat crumpled, imperfectly fissile clay slate. Under the microscope it has a banded and streaky appearance, due to narrow and curving belts of carbonaceous matter and to streaks of fine aggregates of brown biotite. The clearer parts evidently consist of a very fine microcrystalline aggregate of quartz and feldspar, and contain scattered clastic grains of quartz and twinned feldspars. The clay slate is penetrated by irregularly developed fine-grained aggregates of calcite, accompanied by anhedral pyrite. The calcite very evidently replaces the substance of the clay slate.

The second specimen is a black, fissile clay slate, traversed perpendicularly to the schistosity by a great number of narrow quartz veins containing pyrite, arsenopyrite, and a little zinc blende. The slate is free from sulphides. This clay slate is an almost cryptocrystalline mass, traversed by straight, but not very sharply marked, streaks of calcareous matter. Under highest magnifying powers the substance of the slate is resolved into a fine aggregate of at least two substances of different indices of refraction; many of the larger grains show fibrous undulous extinction. In all probability we have in this rock an intimate mixture of quartz and kaolin. Small and perfect prisms of tourmaline and a few minute sericite foils were noted. The rock is cut by sharply defined quartz veins, in places containing a little calcite and sharply defined crystals of pyrite. They are excellent illustrations of the comb-quartz veins, showing a growth of small crystals next to the walls and then a second generation of coarse crystals reaching entirely across the veinlets. Most of the rock is fresh and unaltered, even when adjoining the veins; but in some places a silicification spreads from the veins in irregular blotches, sometimes following the schistosity. These silicified parts are marked in ordinary light by a replacement of the granulated and dusty argillite substance by a clearer quartz mass, and in polarized light by a coarser, though still fine, aggregate of microcrystalline, interlocking quartz grains and scattered particles of calcite.

These two rocks show that a silicification may take place when the country rock is quartzose and contains no constituents which can easily be acted upon by the solutions. Mass action then becomes predominant, and the solutions containing alkaline carbonates, carbon dioxide, as well as silica, deposit the latter, and some of the kaolin is possibly removed. But when the rock contains feldspars and biotite, chemical reaction between the solutions and the rock produces a deposition of calcite, pyrite, and in most cases also of sericite.

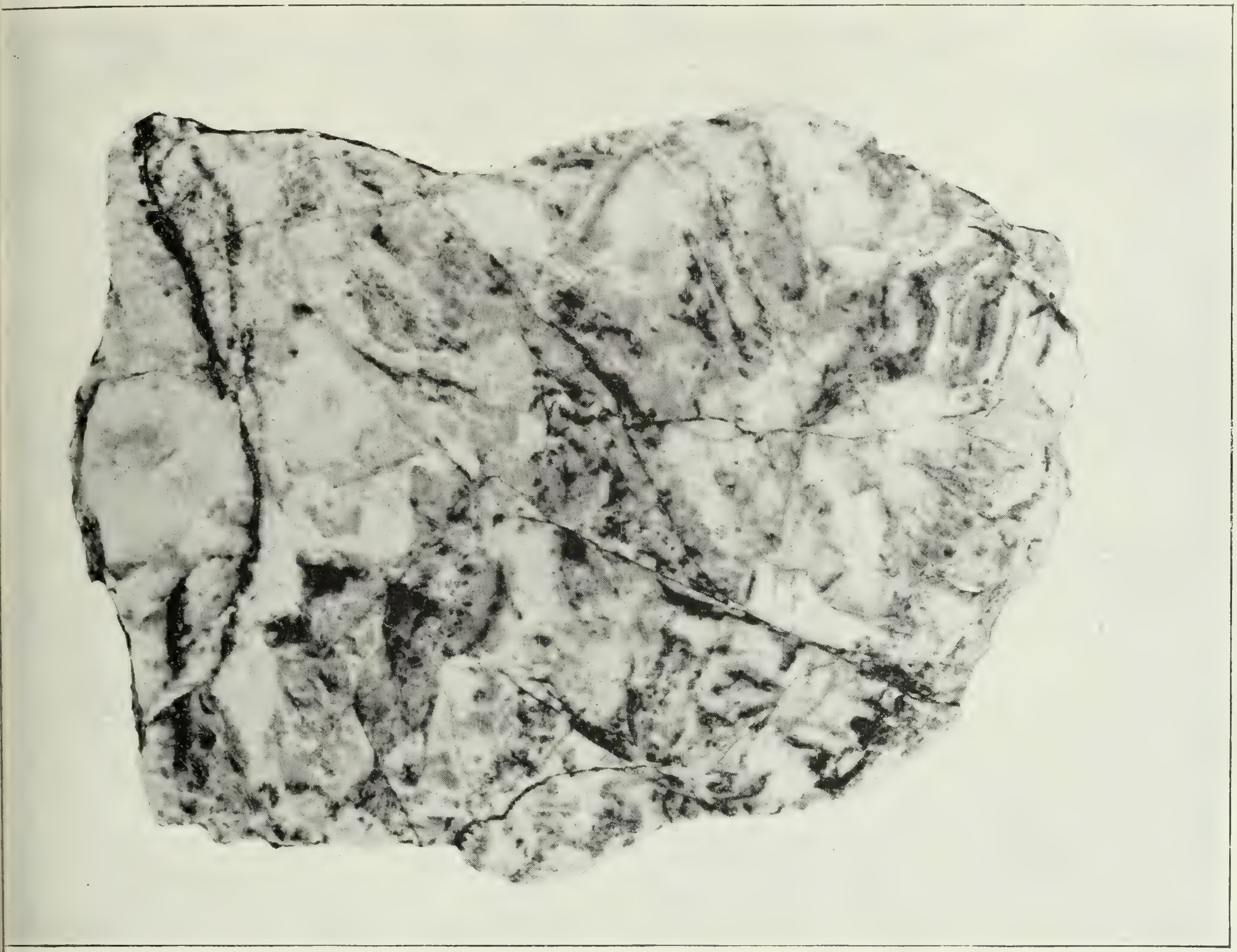
North Pole type.—This division includes the wide, composite veins in argillite and is characterized by a smaller quantity of free gold of rather low grade, together with finely divided sulphurets which usually are rich in gold. The amount of free gold varies from a few per cent up to about 40 per cent. The sulphurets consist chiefly of arsenopyrite and marcasite. Chalcopyrite, galena, and blende are uncommon. Accessory minerals are cinnabar, tetrahedrite, mercurial tetrahedrite, stibnite, and tellurides. The principal gangue is quartz; on secondary seams calcite appears. Chromium mica and roscoelite (vanadium mica) also occur. The ore is usually normal filling, more rarely replaced country rock. The alteration of the slate comprises chiefly a pyritization, occasionally also a silicification; porphyry dikes contained in the argillite are sericitized and partly also carbonatized.

In the North Pole mine the normal ore is a coarse, typical quartz with strong tendency to comb structure. The large crystals show concentric lines of growth upon which the new individuals develop with the same orientation as in the underlying crystals. The comb quartz contains in fine distribution idiomorphic arsenopyrite and less well-developed pyrite. Sometimes the arsenopyrite appears in several sharply defined thin crusts of primary deposition, each generation again covered by comb quartz. Aqueous inclusions of irregular form are common in the quartz. The only difference between barren quartz and ore is in the sulphides contained in the latter.

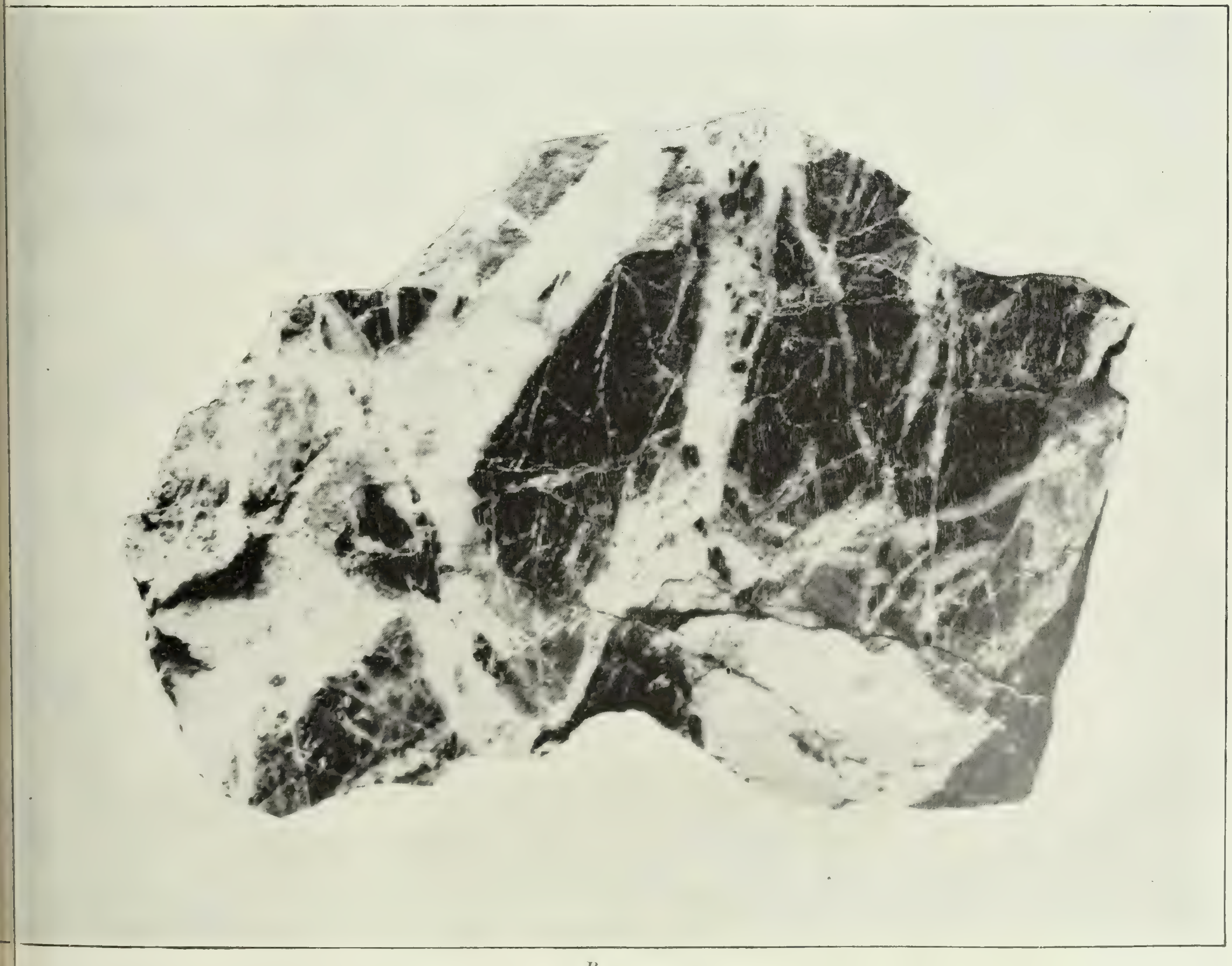
The country rock is siliceous and consists of closely packed, minute, allotriomorphic quartz grains. Between them lie a few fibers of sericite. The planes of the sedimentation are marked by streaks of black carbonaceous material. The principal alteration consists in the development of pyrite in small cubes. This pyrite may in places form larger aggregates, but the latter are always poor in gold and silver.

Secondary changes are frequent in the ore. In many places the quartz shows undulous extinction and is traversed by crushed zones. Whole masses of primary quartz with arsenopyrite in concentric deposition are crushed and recemented by quartz. This produces the peculiar brecciated appearance shown in Pl. LXVIII, *A*, with concentric streaks of arsenopyrite running in many directions and frequently sharply interrupted. In the secondary quartz are scattered sharply defined pentagonal dodecahedrons of pyrite. A third and latest phase of the vein formation is the introduction of calcite along narrow cracks throughout the barren as well as the rich quartz. With the calcite, pyrite and arsenopyrite again recrystallize.

A thin section of rich telluride ore from the North Pole is shown on Pl. LXIX, *B*. The principal mineral is hessite, which is lined with native gold and also contains small masses of another pale-yellow telluride. These minerals occur in apparently primary quartz.



A.



B.

In the Columbia mine similar relations prevail. The ore is prevailingly a quartz filling showing comb-quartz structure. The argillite is a very fine-grained but clear quartz mosaic, containing abundant streaks of organic matter. Cubes of pyrite are often inclosed in this carbonaceous substance. A slight silicification may have taken place. The argillite is cut by well-defined quartz veinlets, which again show a late infiltration of calcite. Dikes of a very altered igneous rock of doubtful original character are also cut by the vein. A specimen of altered porphyry from the lowest tunnel level consists of sericite fibers, calcite, and a few anhedrons of pyrite.

The rich shipping ore, ordinary specimens of which assayed 245 ounces gold and 166 ounces silver per ton, is a greenish-gray quartz of varying grain. Much of it is very fine grained and almost flinty, and darkened by finely distributed sulphurets. In some places fragments of a greenish-gray altered rock are included in quartz, the color being due to the finely divided roscoelite. Fibers of this mineral are also scattered through the whole rock. The sulphurets consist of pyrite, chalcopyrite, zinc blende, and a black mercurial tetrahedrite, besides much native gold. The latter occurs in intergrowth with the colorless or brownish zinc blende and the tetrahedrite, but not with the pyrite. It also is found intergrown with roscoelite wherever that mineral is abundant. In the prevailing mass of quartz lie small, well-defined inclusions, probably of argillite; these consist of microcrystalline quartz with a little sericite.

The prevailing mineral is a partly idiomorphic normal vein quartz, the grain of which varies considerably. The roscoelite is distributed throughout the quartz in fine aggregates of greenish fibers of strong double refraction. The specimens show no evidence of secondary crushing or deposition.

At the Golconda mine the big quartz vein splits up into stringers, and there is more ore derived from alteration of the country rock than at the other mines. The argillite here approaches normal clay slate, extremely fine grained, with curved streaks of carbonaceous matter. The groundmass seems to consist chiefly of interlocking and very minute quartz grains, together with a little chlorite and isolated crystals of tourmaline and zoisite. The altered rock near the veins contains green spots, due to some chromium mineral, probably fuchsite, besides much pyrite in well-developed crystals. In one specimen were found abundant small and wedge-shaped crystals of marcasite, sometimes also star-shaped, compound crystals of the same. The argillite is cut by veinlets of granular quartz with a little sericite and pyrite.

Dikes of undeterminable porphyries also occur in the mine, and some of them are sufficiently mineralized to be regarded as ore. They are dull grayish, or grayish green, and contain a little pyrite. One of these, collected from the dump, consists chiefly of sericite in ragged bunches of fibers, and a secondary quartz mosaic, as well as abundant and sharp pyrite crystals. Another dike, from the fourth level, which was considered as ore, consists largely of an extremely intimate mixture of dolomite and quartz, with a little pyrite. Veinlets of quartz, cut again by still later veinlets of some carbonate, traverse the slide. The original rock was probably a basic dike. Possibly the chromium found in the altered rocks is derived from this source.

The rich shipping ore found in the Golconda is similar to that from the Columbia. It consists of a dull-greenish rock of extremely fine-grained quartz, colored by films of roscoelite, and containing pyrite as well as abundant star-shaped marcasite crystals. This rock, which probably is an altered and silicified argillite, contains vugs and veinlets filled with coarser quartz, with native gold, chalcopyrite, pale-brown zinc blende, and probably tetrahedrite. Fine-grained chalcedonic veinlets also cut the rock. Altogether, the ore seems to be a crushed and greatly altered argillite.

In the Mountain Belle the normal quartz filling again appears. The quartz cements fragments of argillite, which is decidedly silicified and contains cubes of pyrite.

The ores of the Ibex vein are composed chiefly of normal quartz filling, the structure giving clear evidence that it was deposited in open space. Fragments of argillite are included in the quartz. These are decidedly silicified and converted to a quartz mosaic coarser than that of the normal rock. Pyrite and small fibers of sericite also appear in it. The ore minerals are finely divided native gold, pyrite, arsenopyrite, and a little pyrargyrite and cinnabar. The latter occurs on secondary fissures in the vein quartz.

The richest ore of the Ibex is a dark-gray breccia of quartz and argillite, the latter composed of microcrystalline quartz and a little sericite, carbonaceous matter, and pyrite. Most of the fragments are sharply defined and cut by quartz veins showing comb structure; but in other places there is an ill-defined mixture of argillite and quartz, strongly suggesting a mud of crushed argillite, between the particles of which the quartz crystallized. In this mixture of quartz and argillite are particles of native gold, together with coarse pyrite and finely distributed arsenopyrite. Several belts of secondary crushing traverse the specimen, and in these is much sooty, fine-grained arsenopyrite, as well as a little gold in fine wires.

Somewhat different from these examples is the Cougar vein, in which there is but little quartz, but much crushed argillite constituting the principal ore. The ore contains a considerable amount of silver, one sample assaying 0.68 ounce gold and 23.88 ounces silver per ton. The ore is composed of argillite, consisting of a very fine-grained and sharply defined quartz mosaic, with a few shreds of sericite and scat-

PLATE LXIX.

PLATE LXIX.

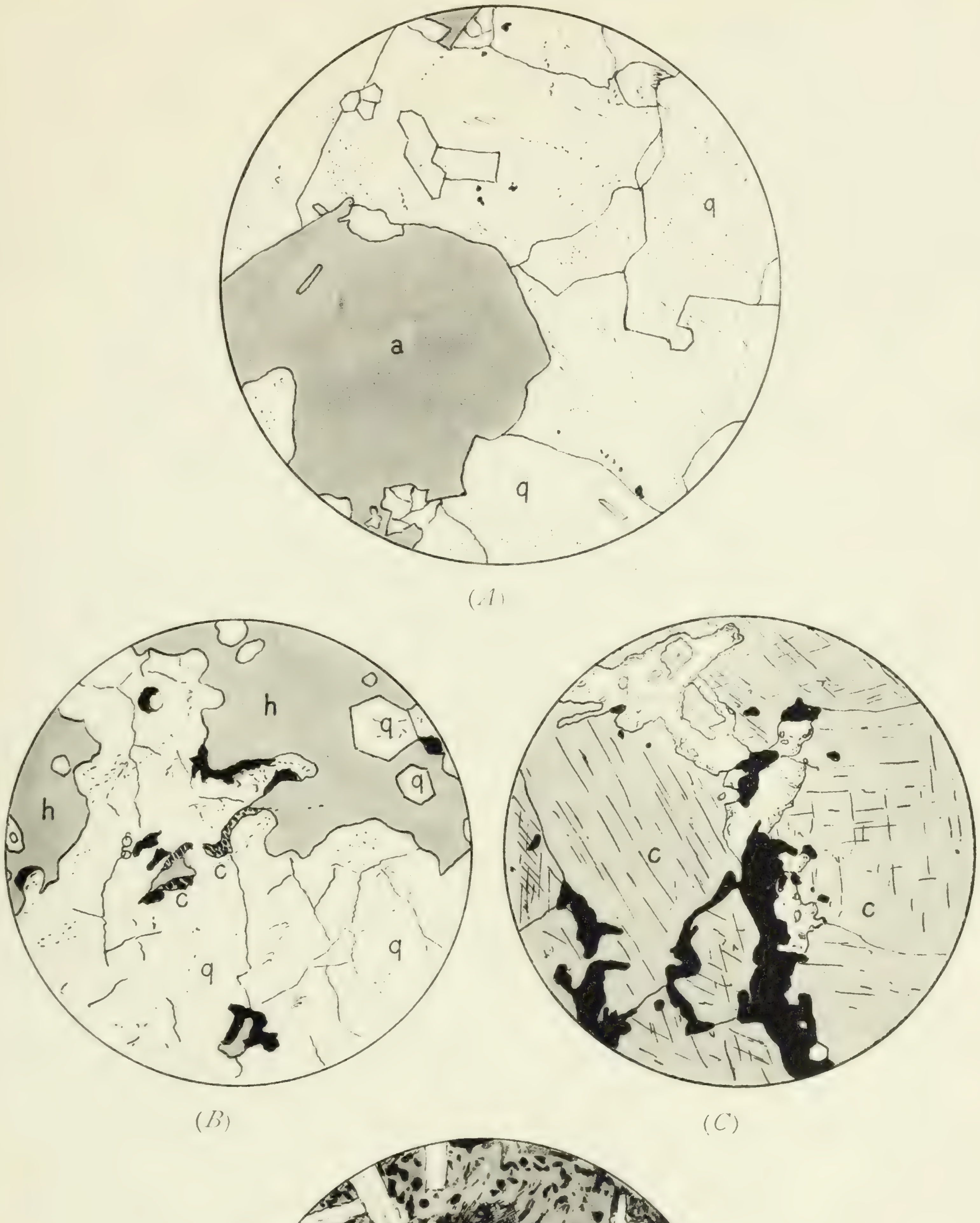
THIN SECTIONS SHOWING STRUCTURE OF ORE.

A. Normal vein quartz with arsenopyrite, from Imperial mine, Cable Cove; q, quartz; a, arsenopyrite. Magnified 16 diameters.

B. Telluride ore from North Pole mine; q, quartz; h, hessite; g, gold; c, calaverite?. Magnified 24 diameters.

C. Coarse gold in calcite with quartz; Great Northern mine, Canyon; c, calcite; q, quartz; gold, black. Magnified 12 diameters.

D. Copper, replacing feldspar in Triassic andesite or basalt. Copper Union, Copper Butte district; f, feldspar; c, chlorite; cp, copper. Magnified 120 diameters.



THIN SECTIONS SHOWING STRUCTURE OF ORE

tered crystals of pyrite and marcasite. Veinlets of quartz, with needles and star-shaped compound crystals of marcasite, traverse the argillite.

Many veins near Alamo belong to this type, and in most of them the ore contains bright-green spots, partly in the quartz, partly in the argillite. This color is due to chromium, and it is believed that the mineral causing it is a very finely divided chromium mica. It is especially prominent in the Little Giant mine, and may be explained by the fact that serpentine, always containing chromium, occurs in close vicinity to the vein; but it is also found in the Quebec, Wilson, and other veins a mile or two distant from serpentoid rocks.

Red Boy type.—This type consists of veins in argillite, similar in their filling to those of the North Pole type, but distinguished by predominant free gold of a low degree of purity. The gold makes up 60 to 90 per cent of the assay value, and varies in fineness from 500 to 600, the rest being silver. Sulphurets amount to 5 per cent at most, and are poor, the concentrates rarely assaying more than $30 per ton. They consist chiefly of pyrite, with a little arsenopyrite and chalcopyrite, or of argillite penetrated by veinlets of quartz, usually with comb structure. The gangue consists of normal vein quartz mixed with fragments of argillite. To this type belong the Red Boy veins, the Bonanza, and the Mammoth. At the Red Boy mine the black argillite seems altered only by the introduction of pyrite, while dikes of a porphyritic rock which can not be identified have suffered alteration to calcite and pyrite, accompanied by microcrystalline quartz.

At the Mammoth mine the country rock is partly granodiorite, partly a siliceous argillite. The latter has suffered no change, except the introduction of some pyrite. The granodiorite is carbonatized to a considerable degree. The ore, which forms thick bodies, consists of brecciated slate and granodiorite cemented by normal vein quartz, containing coarse, pale gold, together with a little pyrite and arsenopyrite. Closely associated with the gold is a dull-green vanadium mica, probably roscoelite. This forms irregular blotches and small aggregates in the quartz, and often surrounds the gold, as shown on Pl. LXX, *D*. There is no reason for believing that the rich ore which occurs near the surface is not due to primary deposition. The rich quartz is traversed by crushed zones and small slipping planes, often coated with gold. Irregular seams of calcite, the latest mineral formed, cut across the quartz. In other parts of the mine the ore is a breccia of sharp argillite fragments. The argillite is very siliceous, appearing under the microscope as a microquartzite. The metasomatic change consists only in the introduction of cubes of pyrite and slender prisms of arsenopyrite or marcasite. The cementing mass is chiefly calcite, coating the argillite in pretty crusts. The calcite contains inclusions of normal vein quartz.

IMPREGNATIONS.

In certain districts in which the vein-forming solutions have been especially active there is another type of deposit which has received little attention because the tenor in gold is usually very small. In this type whole masses of argillite, generally following the roughly defined planes of sedimentation, have been subjected to partial replacement, and no distinct fissures are found. The argillite is somewhat crushed, and quartz has developed on little seams and in nodules. Scattered crystals of pyrite replace the argillite, and there may also be a little dolomite and stains of chromium mica. Strata of argillites several hundred feet thick show these evidences of mineralization and contain throughout traces of gold. Examples of these deposits are found in the Alamo and Granite districts.

The presence of chromium mica in nearly all the veins and deposits of the Alamo district is very remarkable. Serpentine, which always contains chromium, is abundant a few miles from Alamo, but the veins contain this chromiummica whether close to or distant from the contact. I should think it probable that the vein-forming solutions ascended into the argillite from underlying masses of serpentine or peridotite.

SILVER VEINS.

Tempest type.—This type is very similar to the Cable Cove type among the gold veins. It occurs in the granodiorite of the Greenhorn Mountains. The gangue is quartz, forming a normal filling and containing very abundant pyrite, arsenopyrite, and zinc blende. There is little or no galena and no rich silver sulphides. The ore is accompanied by normal, sericitic-carbonatic alteration of the country rock. A little calcite fills secondary cracks in the quartz. In the Carbonate vein, which crops near serpentine, dolomite and a pure chromium mica are abundant.

Greenhorn type.—The deposits of this type are normal, simple quartz veins containing, intergrown with the quartz, tetrahedrite, and, more rarely, argentite and pyrargyrite. Representatives of this class are the Intermountain and Intrinsic veins on Greenhorn Mountain, the Monumental in the Granite district, and the veins of Pedro Mountain in the Rye Valley district.

Mineral type.—The only representatives of this type are the deposits at Mineral, Idaho, near Snake River. They are veins or irregular bodies connecting with fissures and containing pyrite, chalcopyrite, tetrahedrite, galena, and zinc blende, intimately intergrown with one another and with calcite gangue. The ores are in part surely formed by replacement of the country rock, a greenstone or greenstone tuff. The ores are ordinarily not rich in copper or lead. Average good ore

PLATE LXX.

PLATE LXX.

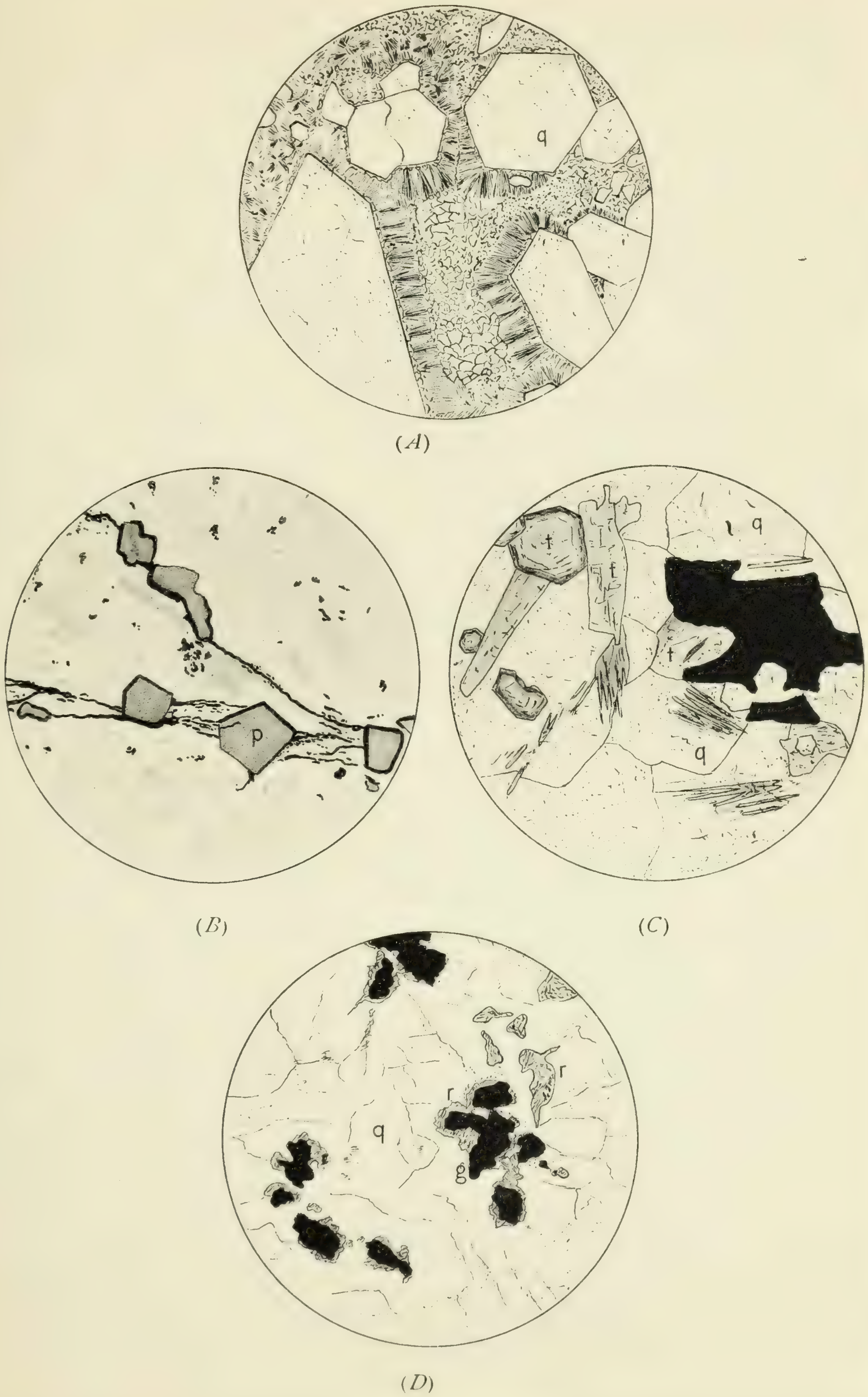
THIN SECTIONS SHOWING STRUCTURE OF ORE.

A. Comb quartz, cemented by chalcedony. Banzett mine, Robinsonville. Polarized light; q, quartz; fibrous and fine-granular aggregates, chalcedony. Magnified 12 diameters.

B. Crystals of pyrite, forming by replacement in chloritic diabase along cracks filled with calcite. Great Northern mine, Canyon. p, pyrite; black, calcite, also lining pyrite crystals; shaded in definite areas, chlorite. Magnified 12 diameters.

C. Tourmaline ore, Copperopolis, Quartzburg district. q, quartz; t, tourmaline; black, chalcopyrite. Magnified 28 diameters.

D. Gold-quartz ore. Belle of Baker, Mammoth mine, Sumpter; q, quartz; r, roscoelite; g, gold. Quartz has normal coarse-grained structure. Magnified 28 diameters.



THIN SECTIONS SHOWING STRUCTURE OF ORE

contains 0.28 ounce gold and 55.92 ounces silver. A peculiar feature is the extremely intimate intergrowth of galena and zinc blende into concentric aggregates.

COPPER DEPOSITS.

GENERAL STATEMENT.

Deposits in which copper constitutes the most valuable metal are rather extensively scattered over the eastern part of the region under discussion. Most of the deposits are contained in Triassic lavas interbedded with sedimentary rocks of the same age. While the gold and silver veins may contain some copper and the copper deposits almost always contain some silver and at least a trace of gold, the copper deposits form a separate class, with well-marked and distinctive characteristics pointing to a very different origin from that of the gold and silver veins. The copper deposits may be classified as follows: The Seven Devils type, the Tourmaline type, and the Snake River type. The first two are of rare occurrence.

SEVEN DEVILS TYPE.

This type includes contact deposits of irregular bodies of chalcopyrite and bornite between limestone and diorite. As gangue appear garnet, epidote, and other contact minerals. This type is represented only by a small prospect near Medical Springs (see p. 731).

TOURMALINE TYPE.

This type is characterized by chalcopyrite and pyrite associated with a gangue of quartz and tourmaline. The deposits form fissure veins or irregular replacements probably connected with fissures. Only two representatives of this type have been found.

The Copperopolis mine, on the east fork of Dixie Creek in the Quartzburg district, is the first. Brown fibrous tourmaline (blue and brown in thin section) is intimately intergrown with quartz (Pl. LXX, *C*), containing very abundant, mostly round, aqueous inclusions. The quartz is in part normal, coarse, vein quartz, in part idiomorphic, in part finer-grained allotriomorphic. The latter as well as the intermixed dirty-brown tourmaline were formed by replacement of the country rock, a diabase. The chalcopyrite is intergrown with quartz and tourmaline.

The Jessie vein in the Mineral district is the second. This is a fissure vein in diorite, accompanied in the hanging wall by a dike of basalt. The vein matter is a black gangue with massive pyrite and chalcopyrite. Thin sections of the ore show a somewhat interlocking, fairly coarse aggregate of quartz, calcite, and dolomite, all in anhedral development. In addition, a mineral which greatly resembles vesuvianite is present, also chlorite and an acicular or prismatic blue or dirty-brown tourmaline. Thin steel-gray lamellæ of specularite, single and in bunches, are embedded in both quartz and calcite. In translucent light the thin plates are deep red. Pyrite and chalcopyrite are intergrown with quartz, tourmaline, and specularite. The ore has been crushed, and along the cracks calcite has infiltrated.

This mineral combination is very remarkable for fissure vein. Especially is the occurrence of specularite noteworthy. It emphasizes the opinion given in another place[1] that the tourmaline veins are, as a rule, connected with deep-seated processes and formed under higher pressure and temperature than ordinary hydrothermal gold and silver veins.

SNAKE RIVER TYPE.

In general this type is characterized by finely distributed chalcocite or bornite, more rarely chalcopyrite, in Triassic lavas or tuffs. Metallic copper or malachite is sometimes present. The ores carry a little silver, and sometimes also gold. These deposits seem to be largely of metasomatic origin. The distribution of the sulphides is sometimes irregular, but more commonly follows well-defined directions, probably determined by systems of joints. A connection with sharply defined fissures can rarely be observed. The gangue minerals with which the sulphides are associated are quartz, epidote, actinolite, or chlorite, and according to the local prevalence three subtypes may be distinguished.

Epidotic subtype.—In this, chalcocite is associated with epidote in small replacement veins traversing the rock, and native copper occurs as a secondary product. At the North American Copper Company's prospects at Copper Union the ore-bearing rock is a soft, dark-green, very altered Triassic basalt, in places containing small amygdules of calcite. With the naked eye may be seen irregular grains of chalcocite and a little metallic copper, the latter mostly contained in the white veinlets traversing the slide. Under the microscope the basaltic character of the rock is apparent. Phenocrysts of labradorite are contained in a dark groundmass full of small prisms of the same mineral. Chlorite is very abundant in the feldspars as well as in small vesicules throughout the mass. The augite has disappeared completely. Along lines of pressure and deformation small replacement veins of chalcocite inclosed in epidote are noted; no other mineral accompanies the chalcocite. Throughout the section very finely divided metallic copper is distributed, especially abundant is it in little veins filled with zeolite, which corresponds well with natrolite and occurs in fibrous masses with radial structure. Much copper is also contained in the groundmass and in the feldspars of the rock, but it replaces the minerals in which it occurs and is accompanied by chlorite, a little quartz, and a considerable amount of reddish or brownish limonite or hematite, which seems to surround the aggregates of chlorite near the copper (Pl. LXIX, *D*).

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[1] Metasomatic processes in fissure veins: Trans. Am. Inst. Min. Eng., Vol. XXX, 1901, p. 67.

Neither chalcocite nor copper in their present form is a primary constituent of the rock. The chalcocite has been introduced first and the native metal seems a secondary product derived from the sulphide. While a secondary process, the formation of native copper can not justly be said to be due to surface decomposition, for it is clearly connected with the chlorite and the zeolites which may form at great depth. While there is thus no reason why the metallic copper could not occur throughout larger masses of rocks and on a larger scale, the fact seems to be that its occurrence is of subordinate importance to that of the chalcocite. The latter certainly has formed along cracks and joints, but is, nevertheless, not concentrated in well-defined fissure veins.

In the Snake River Canyon many similar deposits occur. Those especially examined were located near Ballards Ferry. The prevailing rock at McDougals camp, 2 miles below Ballards Ferry, is a brownish-gray volcanic tuff, probably of Triassic age. It contains clastic grains of quartz, feldspar, and a variety of fine-grained lavas. The cementing material is a finer mass of the same substances and irregularly distributed chlorite. Amygdules of calcite are common. Some of the prospects have the appearance of small fissure veins with a well-defined filling of white quartz, epidote, and massive chalcocite, the latter especially intergrown with epidote. The larger deposit forms a zone at least half a mile long and from 8 to 30 feet wide, in which an impregnation of calcite is noted. The thin sections show that the rock is fractured and deformed. On these fractures chalcocite, intimately intergrown and inclosed in epidote, has formed as narrow replacement veins. In other places isolated grains of chalcocite are surrounded by irregularly spreading epidote. Malachite appears as a product of decomposition of the chalcocite, but there is no metallic copper. The cryptocrystalline malachite forms veinlets and nests replacing the cement of the tuff.

Actinolitic subtype.—Deposits of this type were examined on the copper claims near the Snowstorm mine, not far from Sanger. The rock is here a dark-green diabase, in which some of the augite still remains, as well as some of the ilmenite, the latter otherwise altered to leucoxene. Throughout the rock light-green needles of amphibole are abundant as a secondary formation; the amphibole occurs throughout the feldspars, and especially along the fractures. Associated with it are irregular grains of chalcocite and bornite. Secondary quartz forms good-sized nodules in the rock and is also intergrown with bornite. Some malachite has formed from the sulphides and occurs intergrown with quartz.

Chloritic subtype.—This is best represented by the Iron Dike deposit. A large mass of a Triassic greenstone of uncertain original character is here shattered and filled with irregular veinlets of quartz with pyrite and chalcopyrite. Besides being thoroughly filled with chlorite it is certainly also largely replaced by quartz and pyrite, the latter often surrounded by chalcopyrite. Heavy bodies of pyrite and chalcopyrite occur at this place and are in all probability due to a complete replacement of the chloritic rock. This ore contains a little gold and silver, as well as occasionally some galena and zinc blende.

The River Queen deposit should perhaps be referred to this type. It has an irregular, vein-like form, and occurs in an old chloritic rhyolite with phenocrysts of quartz. The ores are cuprite, chalcocite, and pyrite.

The Standard mine, in the Quartzburg district, may also doubtfully be referred to this type. It occurs as a narrow, ill-defined vein, in a chloritic diabase, and is accompanied with small calcite. The ores are chalcopyrite, intergrown with the rare cobalt-arsenide, smaltite, and contain both gold and silver.

COMPARISON WITH GOLD-QUARTZ VEINS.

In the Snake River type of deposits the characteristic association is that of copper sulphides with epidote, amphibole, or chlorite, and in part, also, with quartz. This is in great contrast to the gold-silver veins, where the first three minerals are unknown constituents of the gangue. Further, the copper minerals do not occupy sharply defined and persistent fissures like the gold and silver veins, but appear along joints and small irregular fissures. The ores in their present form are clearly of secondary origin; they are not primary constituents of the rock. They are always, as far as known, associated with the Triassic greenstones, old basalts, andesites, and rhyolites. The difference between these copper deposits and the gold-silver veins is radical, alike in form, substance, and metasomatic processes. They were certainly not formed by the same or even by similar solutions. I would regard them as having probably been formed by a sort of lateral secretion, and by dilute, perhaps cold, solutions belonging to the general circulation of the ground water. The source of the metals was probably in the surrounding old lavas. The active metasomatic processes show a close connection with the general hydrometamorphism, which gradually changes the character of igneous rocks by the formation of amphibole, chlorite, quartz, epidote, and zeolite, while the gold quartz veins are probably due to thermal ascending waters. There is an undoubted parallelism between these copper deposits and those of the Lake Superior region, for both occur in part as replacement veins in amygdaloid rocks. But the Lake Superior veins contain chiefly metallic copper, the sulphides being very rare, while here the reverse is true.

OXIDIZED ZONES OF THE COPPER DEPOSITS.

In most cases the oxidized part of the copper deposits is very superficial, and sulphides, chalcopyrite, as well as chalcocite and bornite, appear immediately or only a few feet below the surface. A little malachite often appears on the surface, but sulphides are usually immediately associated with it. The large sulphide mass of the Iron Dike was covered by a brown shallow crust in which practically no copper was present. Immediately below this pale and partly decomposed pyrite appeared, and the chalcopyrite began only a few feet below the pyrite.

ECONOMIC CONSIDERATIONS.

Among the copper deposits of this region are a vast number of prospects, but thus far no producing mine. Only two or three prospects have made small shipments of high-grade ore. It is, of course, well known that the development of a low-grade copper mine is an enterprise demanding much time and money, differing in this respect from that of an ordinary gold-quartz mine. In the latter a mill adapted to the requirements of the ore and the size of the vein may be rapidly erected and the mine become producing in a short time. For low-grade copper ores very extensive and very carefully planned reduction works are necessary. Ores consisting of coarse pyrite and chalcopyrite with chlorite-quartz gangue, like the Iron Dike, are easy to concentrate and, provided the ore contains enough copper, will prove valuable. Ores containing chalcopyrite and tourmaline will be difficult to concentrate, owing to the high specific gravity of the latter. The majority of the deposits are zones of impregnation with chalcocite in fine distribution. These have been most widely advertised, and presumably ill-informed companies have issued glowing reports apt to mislead the unwary. Copper lodes 4 miles in length and a mile in width, with inexhaustible supply of 4 per cent ore, have been claimed to exist. The fact that ores in the Lake Superior region containing less than 1 per cent of metallic copper have been successfully worked has been duly placed before the public. As a matter of fact, most of these impregnated zones will not contain more than 1 or 2 per cent of copper, and the width ranges from a narrow seam up to 30 feet. The lowest grade of copper ore which can be considered in eastern Oregon, under present conditions, is one containing 3 to 4 per cent of copper, provided that large quantities of it exist. The successful treatment of this ore offers considerable difficulty. Leaching processes can probably not be employed, for the ore contains too much easily dissolved silicates of magnesia, lime, and iron. Concentrating will be difficult and attended with great loss, for fine crushing will be necessary and the chalcocite will form rich slimes. Should large bodies of ore containing metallic copper be found, these difficulties will be largely obviated, but at present there is no great probability of this. These remarks are not meant to discourage the search for and the development of the copper properties, but only to point out actual facts. Paying copper mines may well be developed in eastern Oregon, but it will be only by careful conservative work by men who understand the problems presented.

PLACER DEPOSITS.

EXTENT.

The placer deposits indicate the extent of the gold belt of eastern Oregon, being widely scattered over the whole area, from the sands of the Snake River on the east to the gravel bars of John Day River on the west. They were the first deposits discovered by the pioneer miners and yielded their millions in early days. Though the output is greatly diminished, the placers are at the present time by no means an unimportant factor in the gold-mining industry of the State. Oregon produces placer bullion to the value of about $300,000 annually; the amount is, however, slowly diminishing. The placers contribute about one-fourth to one-fifth of the total production of gold and silver (see p. 572).

The placer-mining districts are distributed as follows: On the east the Snake River bars still contribute some fine gold. In the Eagle Creek Mountains and at Sparta a small but steady production is maintained. Sparta, especially, was noted for its rich gulch diggings in early times. The belt extending from Connor Creek by Weatherby, Chicken Creek, Rye Valley, Humbolt, Clarks Creek, and Malheur was formerly the most important gold-mining region in the State and still maintains a diminishing production.

The Virtue placers, near Baker City, were long ago exhausted. West of Baker City is the gold belt of the southern Elkhorn Range, with the once celebrated camps of Auburn, Pocahontas, and Minersville. The headwaters of Powder and Burnt rivers, as well as those of Granite Creek, including the districts of Sumpter, Granite, Robinsonville, Bonanza, and Gimlet, may be said to form the central placer-mining region of the Blue Mountains. These placers, while not as extraordinarily rich as some of the others, have maintained a steady though small production, and seem likely to continue to do so for many years. Finally, on the western side are found the isolated districts of Susanville, Dixie Creek, and Canyon Creek, the latter having the reputation of having been the richest placer camp in the State. Both at Susanville and at Canyon a fairly steady production is maintained. Farthest west are the small placers of Fox Creek and Spanish Gulch, on Crooked River, the latter locality 60 miles west-southwest of Canyon.

GEOLOGICAL CHARACTER.

With few exceptions the placers are gravel deposits contained in the beds of the present streams and gulches, or bars and benches deposited by the same water courses at a former higher level; these benches are rarely found more than 200 feet above the present stream bed; most frequently they are 50 to 100 feet above the same. The depth of the gravels seldom exceeds 50 feet and is ordinarily much less. The bed rock may be any one of the formations found in the region, sometimes even Neocene volcanic rocks. The placers are thus not connected with any certain rock; it may be said, however, that they are most abundant in the districts where intrusive diorites, granites, and serpentines break through older sedimentary series. They are, as a rule, absent in the large granitic areas (northern Elkhorn Range) and in extensive areas of old sedimentary rocks. They are also absent in the great Neocene volcanic areas. In mountains which have been covered by glaciers during the ice epoch placers are rarely found. Examples of this are found in the Cornucopia, Cable Cove, and Greenhorn districts. No doubt gold-bearing gravels existed there before the advance of the ice streams, but the latter have dislodged the gravels and scattered the gold among the moraines, and the time since the close of the Glacial epoch has been too short to permit a new concentration of the gold. As a rule, in these districts placers are found below the terminal moraines.

All this means that the placers were chiefly deposited by the present streams at their actual level or at a former higher level. Placers antedating the present drainage system are of rare occurrence. This is not surprising when we consider that the drainage systems of the old mountain areas had been outlined and eroded long before the Neocene period.

According to their geological age the placers may be divided into:

1. *Prevolcanic* (*Eocene or early Miocene*) *gravels.*—Deposits of this age are preserved only when covered by volcanic flows. Owing to the fact that these flows mainly covered the foothills and the lower part of the mountains, and no uplift accompanied by deep erosion has occurred since, these channels mostly lie below the present drainage level. While many of them doubtless are rich in gold, it will be difficult to find them and still more difficult to work them profitably. The only places where these gravels have been worked are at Winterville and Parkerville, on the headwaters of Burnt River. It does not seem altogether impossible that new channels of this character might be found in this vicinity. The great influx of water into inclines and shafts would greatly increase the cost of working. Working placers by means of shafts has been successful only in very rich placer mines. The banks of these pre-Neocene gravels are only about

15 feet high. Most of the gold is coarse and lies on the bed rock. The Winterville pre-Neocene channel was a smaller stream of no great importance. It is sometimes stated that it was part of a large channel which traversed the Blue Mountains. There is no foundation for this view.

2. *Intervolcanic gravels.*—The volcanic outbreaks flooded the lower valleys with lavas. The upper valleys of Burnt River, Powder River, John Day, and probably also Grande Ronde River were thus dammed and accumulations of gravel at once began. These conditions were also favorable for the concentration of the gold, and placers were formed wherever streams from auriferous areas entered the basins. Of this age are the gravel benches of Sumpter and Canyon. In the case of these, the erosion of the main rivers draining the basins has not proceeded far enough to destroy the connection of the Neocene sediments. But in other cases, in the Granite Creek and North Fork of John Day, the volcanic dam has been cut down much deeper, and of the deposits once filling the basin only small fragments are preserved, as in the case of the Klopp placers (p. 687) and the Griffith gravels (p. 688).

As the canyon cutting proceeded, benches were formed at intervals, and some of these gravels remain at various elevations along the present streams. There does not seem to be any exact limit between the late Neocene and Pleistocene gravels. A gradual erosion was continued during the two periods, interrupted occasionally only.

3. *Pleistocene gravels* thus consist of the lowest benches and the deposits in the present channels. These deposits were the first to be mined and are now practically exhausted, as far as ordinary placer mining is concerned. Some of the deep stream gravels can, however, be profitably dredged.

GOLD AND ACCOMPANYING MINERALS.

The gold varies in size from large slugs and nuggets to the finest flour, of which several thousand particles or "colors" are needed to make 1 cent in value. The largest nugget reported is one said to have been found on McNamee Gulch, near Robinsonville, the value of which is said to have been $14,000. Slugs of a value of several hundred dollars have been found at Mormon Basin and at the Winterville placers (upper Burnt River). Pieces worth $200 and $300 were found at the latter place in the clean-up of the fall of 1900. Ordinarily gold is obtained varying in size from that of a mustard grain to a wheat grain. The purity of the placer gold averages, as usual, higher than that from the veins. A fineness of 900 to 990 is obtained from Canyon Creek, the bench gravels of upper Burnt River, and the Winterville placers. At Susanville and Dixie Creek the gold is 860 fine. At Rye Valley and Mormon Basin the gold varies from 650 to 800. At the Nelson placers it is from 700 to 740 fine. On Olive Creek and at Granite it varies from 680 to 800. The lowest grade is thus about 680, while from a few localities 990 or almost absolutely pure gold is obtained. In a general way, the fineness of gold from one and the same source is apt to increase as the grains grow smaller by attrition, and this has not unreasonably been explained by a gradual dissolving of the silver from the surface of the grains by ordinary surface waters. The flour gold in the bench gravels of upper Burnt River Valley has a fineness of 970, while the coarser gold in the stream bed is only 922 fine. At Canyon the placer gold is 900 fine, but in John Day River, a few miles below the mouth of Canyon Creek, it reaches 990. At Rye Valley the upper benches contain low-grade gold, 750 fine, while the lower benches, the gold of which has been worked over by the stream several times, is 800 fine. Regarding the Snake River gold see pages 759–761.

Platinum should naturally be expected from some placers, especially those in districts with much serpentine, as a connection between this rock and the metal mentioned has often been proved. It has, however, only been reported from one place, viz, Hindman's placers, at the junction of Camp Creek and Pine Creek in upper Burnt River Valley. Mr. Hindman states that a small quantity is found at each clean-up. Magnetite, zircon, ilmenite, and garnet, as usual, accompany the placer gold, the ilmenite often in very perfect, minute crystals. Much cinnabar is reported from Elk Creek, near Susanville. Monazite has not been observed, neither has cassiterite or tin ore been found.

As usual, the gold is largely concentrated on the bed rock, or in the gravels immediately above it, though instances are not wanting of even distribution through 10 or 20 feet of gravels (Nelson placers at Pocahontas). In dredging on Burnt River the top gravel is usually barren and the pay is only obtained from 2 or 3 feet next the bed rock.

The value per cubic yard of gravels in the gravel mines varies greatly. Ordinarily, averaging the content of the whole bank, it ranges from 10 to 35 cents. The stratum on the bed rock is of course much richer. Hydraulic mines working on a large scale may work gravels profitably which average only 2 cents per cubic yard, but such conditions scarcely obtain in this region, where the gravels should at least contain 5 cents per cubic yard. Dredging to a depth of 30 feet may be done for from 3 to 7 cents per cubic yard, but considering the heavy cost of installation and the possibility of losing the pay streaks, gravels for this purpose should ordinarily average 20 to 30 cents per cubic yard. Regarding dredging on Snake River and Burnt River see pages 762 and 766–767.

METHODS OF MINING AND FUTURE POSSIBILITIES.

Placer mining in eastern Oregon has never been carried on upon the large scale prevalent in the California gold belt. The banks are not high, and sluicing or small hydraulic jets throwing at most 500 miner's inches of water have been chiefly employed. The bench gravels of Sumpter, Rye Valley, upper Burnt River Valley, and Canyon are not exhausted, but will continue to yield moderately for many years. No great increase in the yield may be expected from these sources. It is otherwise with mining by elevators or dredges. At present there is only one dredger at work, at Weatherby, on Burnt River, and one elevator, at Malheur. Gravels, which probably are suitable for dredging are found on John Day River below Canyon, on the Middle Fork of John Day, near Susanville, and at many other places. It is in this direction that the placer-mining industry should be expected to advance, and it is very reasonable to expect that the next few years will see many dredgers in operation.

IRON AND MANGANESE ORES.

Incidental to the erection of the smelter at Sumpter, attempts were made to find a suitable flux of iron or manganese in the vicinity. A deposit of hematite is said to occur on the ridge between Powder and Burnt rivers, about 5 miles south of Sumpter, but nothing is known of its extent.

A soft, black manganese ore, resembling pyrolusite, was found on the same ridge about 4 miles west to southwest of Sumpter, and was used in the smelter during the short time in which it was operated. As far as known no other deposits of iron ore occur in this region.

A large deposit of magnetic iron ore is reported from Iron Mountain, a few miles east of Mineral, in Idaho. This ore contains some copper and is also stated to carry a certain percentage of titanium, which, of course, is not in its favor as far as smelting purposes are concerned. During the short time in which the smelter at Cuprum was in operation some of this ore was sent down the Snake River and hauled up to the smelter. As might have been expected, the material was not a success as a flux.

CHROMITE.

It would be surprising if chromite, so often accompanying serpentine, had not been found in the parts of the Blue Mountains where this rock is abundant. A small mass of chromite is exposed in the serpentine close by Gillespie's sawmill, 7 miles south of Prairie. Associated with it is a small quantity of very fine-grained white material which proves to be practically pure magnesite. Heavy float of chromite was noticed close by the placer mines of Winterville, near Bonanza mine.

The mineral is used in the preparation of pigments and in the production of chrome steel. Recently it has also been used as a basic lining in the furnaces of certain metallurgical processes. It is not probable that the occurrences in the Blue Mountains will be economically valuable. Delivered in Baltimore, the value of the ore is only from $20 to $25 per ton, and at the mines in California the value is not more than $8 per ton for 50 per cent ore.

LIMESTONE.

All of the sedimentary rocks developed in the Blue Mountains contain more or less limestone of good quality, interbedded with slates, shales, siliceous argillite, and volcanic tuffs. Very large masses are found in the Eagle Creek Mountains. Its quality is excellent, but distance from lines of communication has prevented its utilization.

The series of rocks exposed near Huntington also contains many beds of limestone of good quality. One of the largest of these masses, several hundred feet wide, is exposed 4 miles above Huntington on both sides of the railroad. At this point are extensive works which supply the larger part of the lime used in the State of Oregon. Other heavy strata of limestone are exposed at the head of Connor Creek and on the hills 4 miles southwest of Durkee.

The argillite series, so greatly developed in the vicinity of Baker City and Sumpter, is less rich in limestone. Smaller lenticular deposits occur about a mile north of the railroad at a point 6 miles southeast of Baker City, and also in the hills 3 miles northeast of Pleasant Valley. At both localities lime has been burned, but only the latter is worked at present. The Elkhorn Range contains a few heavy deposits of limestone of thick lenticular form. The most important of these is exposed on Marble Creek at an elevation of 5,500 feet. Lime was formerly burned there, but at present the works are idle. At Sumpter and west of that place limestone is not abundant. A deposit of apparently limited extent is found half a mile north of the city of Sumpter and has locally been used for smelting purposes. At the Winterville placer mines, a short distance below Bonanza mine, another small mass of limestone appears adjacent to serpentine. No work has been done on this. From this point westward no limestone deposits are known to exist in the area under consideration.

GYPSUM.

Beds of gypsum, or hydrous sulphate of calcium, are not uncommon in sedimentary beds, usually occurring as strata or lenses associated with limestone and shales. It is generally regarded as a chemical deposit resulting from the evaporation of shallow inland lakes. In the area here described one deposit of this mineral has been found which is of sufficient extent to be commercially valuable. This occurs about 6 miles north of Huntington, near the summit of the ridge overlying Snake River Canyon. The deposit attains a total thickness of over 40 feet, and is interbedded with limestone, shales, and volcanic tuffs. Its age is uncertain, though it is not unlikely that it is Triassic.

This is, I believe, the only deposit of gypsum thus far found in Oregon. It is utilized for purposes of fertilizing and for the preparation of plaster of paris. A more detailed description will be found on page 753.

CLAY AND KAOLIN.

Beds of clay suitable for bricks occur in the valley of Powder River and at many other places in the Blue Mountains.

Pure kaolin has been found near the mouth of several of the creeks at the foot of the Elkhorn Range; for instance, on Pine Creek and on Salmon Creek. The deposits, which are from 1 foot to 15 feet deep, cover the gravels of the creek and have the appearance of an extremely fine, almost impalpable white powder, at first glance suggesting an infusorial earth or a rhyolite tuff. Similar kaolin beds were noted in other parts of the region, though not so prominently developed. The origin of this kaolin, which has not been investigated in detail, probably dates from a time when the Powder River Valley was covered by a shallow sheet of water. It is not impossible that this kaolin may be found of some economic importance, if it can be obtained in large quantities sufficiently free from impurities. The mineral is of the nonplastic variety.

COAL.

In the lake beds occurring in many parts of the Blue Mountains thin strata of lignite are occasionally found interbedded with the clays, sands, and tuffs. A long-known occurrence of this kind is at Auburn, near the southern end of the Elkhorn Range. The soft beds underlying the auriferous gravels here contain a thin bed of lignite of poor quality, an analysis of which is given in Raymond's report of 1873. It was made by T. M. Drown, of Philadelphia, and runs as follows: Moisture, 14.68 per cent; volatile matter, 38.95 per cent; fixed carbon, 42.57 per cent; ash, 3.80 per cent; total, 100. The coal is noncoking, and, as the analysis shows, of inferior quality. It is not likely that it will be of economic importance. Another bed of shaly lignite, about 2 feet thick, is found on the southern side of Powder River opposite the mouth of Goose Creek. It is interbedded with tuffs and clays and covered by a basaltic flow. The quality appears inferior and the deposit is probably of limited extent.

Coaly material is also found in the lake beds at the eastern end of Eagle Valley, as well as in lake deposits in the John Day Valley, not far from Prairie.

MINERAL SPRINGS.

Mineral springs occur widely scattered over the area described, but they can not be said to be very abundant. The best-known locality is at Medical Springs, 20 miles north-northeast of Baker City. At this place thermal springs issue from two orifices in a rock belonging to the greenstone series. The aggregate flow amounts to several miner's inches and the temperature is 140° F. The appended analysis is said to show the composition of the waters, which are locally used for medicinal purposes:

Analysis of mineral water from Medical Springs, Oreg.

[Parts per 100,000.]

Constituent.	Parts.
$CaCl_2$	5.552
$MgCl_2$	.466
KCl	.642
NaCl	5.758
Na_2SO_3	.524
Na_2SO_4	50.638
Na_2CO_3	.579
$FeSO_4$	.558
$CaSO_4$	12.175
$CaCO_3$	1.417
SiO_2	9.698
Organic	1.553
Total	89.520

The Virtue mine, in its lower levels, contained a great amount of water of moderately warm temperature. The mine being, unfortunately, closed, no data could be obtained as to the composition of these waters. From the foothills just east of Baker City, near the small stamp mill erected in the outskirts of the city, springs with tepid water are said to issue. Along Snake River a remarkable spring is said to occur at Tartar's ranch, about 8 miles above the mouth of Powder River, where it has formed a considerable deposit of soda.

Hot sulphur springs also exist in the Snake River Canyon on the Idaho side, a mile above Brownlee Creek, and again on the same side a little below Miller Bay.

At the point where the road from Durkee to Rye Valley crosses Burnt River two hot springs issue in the bed of the river just above the water level. The quantity of water is not large, and the water is only moderately warm. It does not seem to be rich in mineral constituents. Just above the bridge calcareous sinter appears and covers an area of several acres. No doubt this has been deposited by now extinct hot springs. The region of upper Burnt River and upper Powder River seems to contain very few waters which might be classed as mineral. In John Day Valley noted springs of hot water issue 9 miles above Prairie, near the mouth of Reynolds Creek, and are locally used for medicinal purposes. Still another hot sulphur spring is reported from Camp Creek about 6 miles south of Susanville.

On the whole the thermal waters of this region may be characterized as weak mineral waters containing a small amount of salts, together with a little hydrogen sulphide.

MINERALS.

Following is a list of minerals occurring in the Blue Mountains, arranged by mining districts:

List of minerals occurring in the gold belt of the Blue Mountains.

	Elkhorn.	Pocahontas.	Sumpter.	Cable Cove.	Granite.	Alamo.	Greenhorn.	Robinsonville.	Bonanza and upper Burnt River.	Susanville.	Quartzburg.	Canyon.	Virtue.	Copper Butte.	Sparta.	Cornucopia.	Lower Snake River.	Connor Creek.	Mineral.	Lower Burnt River.	Rye Valley.	Mormon Basin, Malheur.
Gold	×	×	×	×	×	×	×	×	×	×	×	×	×	...	×	×	...	×	...	×	×	×
Silver	...	...	...	...	×	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	×	...
Platinum	...	...	...	...	...	...	...	...	×	...	...	...	...	...	...	...	...	...	...	...	...	...
Copper	...	...	×	...	×	...	...	...	...	...	...	...	...	×	...	...	...	...	...	...	...	...
Quicksilver	...	...	...	...	×	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...
Pyrite	×	×	×	×	×	×	×	×	×	×	×	×	×	...	×	×	×	×	×	×	...	...
Marcasite	...	...	×	...	×	...	...	...	...	...	×	...	...	...	...	...	...	...	...	...	...	...
Pyrrhotite	...	...	...	...	...	...	...	...	...	...	...	...	×	...	...	...	...	...	...	...	...	...
Galena	×	...	...	×	...	...	×	×	...	×	×	...	...	...	×	×	...	×	×	...	...	...
Zinc blende	×	...	×	×	...	...	×	...	...	×	×	...	...	...	×	×	...	...	×	×	...	...
Stibnite	...	...	×	...	...	...	...	...	...	...	...	...	×	...	...	...	...	...	...	...	...	...
Cinnabar	...	...	×	...	×	...	...	...	...	×	...	...	...	...	...	...	...	...	...	...	...	...
Argentite	...	...	...	×	...	...	...	...	...	...	...	...	...	...	...	...	...	×	...	...	×	...
Chalcocite	...	...	...	...	...	...	...	...	...	...	...	...	...	×	...	...	×	...	...	...	...	...
Chalcopyrite	×	...	×	×	...	...	×	×	...	×	...	...	...	...	×	×	×	×	×	...	...	...
Bornite	...	...	...	...	...	...	...	...	...	...	...	...	...	×	...	...	×	...	...	...	...	...
Arsenopyrite	×	...	×	×	×	...	×	...	×	×	...	...	...	...	×	×	...	...	×	...	...	...
Tetrahedrite	...	...	...	×	...	...	×	...	...	×	...	...	×	...	...	...	...	...	×	...	...	...
Tetrahedrite mercurial (schwatzite)	...	...	×	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...
Freibergite	...	...	...	...	×	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...
Pyrargyrite	×	...	×	...	×	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	×	...
Hessite	...	...	×	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...
Sylvanite	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	×	...	...	...	...	...	...
Quartz	×	×	×	×	×	×	×	×	×	×	×	×	×	...	×	×	×	×	×	×	×	×
Zircon	...	...	...	...	...	...	...	...	×	...	...	...	...	...	...	...	...	...	...	...	...	...
Opal	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	×	...	...
Chalcedony	...	...	×	...	...	...	...	×	...	...	...	...	...	...	...	...	...	...	...	...	...	...
Chromite	...	...	...	...	...	...	...	...	×	...	...	×	...	...	...	...	...	...	...	...	...	...
Cuprite	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	×	...	...	...	...	...

List of minerals occurring in the gold belt of the Blue Mountains—Continued.

	Elkhorn.	Pocahontas.	Sumpter.	Cable Cove.	Granite.	Alamo.	Greenhorn.	Robinsonville.	Bonanza and upper Burnt River.	Susanville.	Quartzburg.	Canyon.	Virtue.	Copper Butte.	Sparta.	Cornucopia.	Lower Snake River.	Connor Creek.	Mineral.	Lower Burnt River.	Rye Valley.	Mormon Basin, Malheur.
Specularite (hematite)			×																×			
Magnetite																			×			
Ilmenite									×													
Pyrolusite			×																			
Limonite	×	×	×	×	×	×	×	×	×	×	×	×	×		×	×			×	×		
Garnet									×					×								
Vesuvianite																			×			
Epidote														×			×					
Tourmaline											×								×			
Natrolite														×								
Erionite																	×					
Serpentine							×	×		×		×										
Fuchsite or mariposite			×		×	×	×															
Roscoelite			×																			
Calcite	×		×	×			×	×				×				×		×	×	×		
Dolomite				×			×	×				×										
Magnesite												×										
Malachite											×			×			×		×			
Calciovolborthite														×								
Scheelite													×									
Gypsum																			×	×		
Chalcanthite																			×			

NOTES TO THE LIST OF MINERALS.

Roscoelite.—This rare mineral is of considerable interest, as it generally has been found closely associated with native gold in gold-quartz veins. First discovered in several small quartz veins near Coloma, Eldorado County, Cal., it has again been found in Boulder district, Colorado, and lately also in Kalgoorlie, western Australia.[1] The mineral belongs to the group of the potassium micas in which the alumina is partly replaced by vanadium. The analyses disagree somewhat, and a definite formula is not as yet established. The original analysis by Genth gave:

Analysis of roscoelite.

Constituent.	Per cent.	Constituent.	Per cent.
SiO_2	47.69	K_2O	7.59
V_2O_3	20.56	Na_2O	.19
Al_2O_3	14.10	H_2O	4.96
FeO	1.67	Total	98.76
MgO	2.00		

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[1] T. A. Rickard: Eng. and Min. Journal, Nov. 17, 1900.

This interesting mineral has been found at several mines in eastern Oregon, always associated with rich ore, and ordinarily much free gold. It occurs abundantly in the recently discovered rich shoot of the Belle of Baker, in the rich shipping ore found some time ago in the Golconda mine, and in a similar rich shipping ore lately discovered in the Columbia mine. The mineral has a dull-greenish color, with a tinge of yellow. It occurs intimately intergrown with quartz in yellowish-green microcrystalline aggregates of tufted fibers, generally so fine that its separation from the quartz is almost impossible. The mineral has high double refraction, but the fibers do not seem to be strongly pleochroic. The gold is frequently intergrown with it or surrounded by it, as shown in Pl. LXX, *D*. An attempt to procure sufficient material for analysis failed on account of the impossibility of separating it from the quartz.

Chromium mica.—The argillites and quartz in many of the mines of the Greenhorn Mountains contain greenish spots which have often been mistaken for copper, but which in reality consist of finely divided chromium mica, fuchsite, or mariposite. The same mineral also occurs at Golconda mine, and the stain is somewhat similar to that of roscoelite, but of a slightly more bluish tinge.

Calciovolborthite.—A mineral allied to this species was found in the Little Baby copper prospect near Gilkeson's ranch, about 25 miles northeast of Baker City. It occurs as bright, citron-yellow scales and aggregates with pearly luster on the black, soft argillite in which the copper prospect occurs. Only a small quantity could be obtained for examination. It is, according to Dr. W. F. Hillebrand, essentially a vanadate of copper, but contains, besides, some sodium, and while corresponding approximately as to its percentage of copper and vanadium with the mineral mentioned, it is probably, in fact, a new species.

Scheelite.—This mineral, recently discovered by Mr. C. King, of Baker City, in the Flagstaff and Cliff mines in the Virtue district, is not altogether unusual in gold-quartz veins. It has been found in such deposits near Grass Valley, Cal., Warren, Idaho, and also in New Zealand.

CHAPTER IV.

DETAILED DESCRIPTIONS OF MINING DISTRICTS.

ELKHORN AND ROCK CREEK DISTRICTS.

GENERAL FEATURES.

The Elkhorn mining district is situated 12 miles west-northwest of Baker City, on the eastern slope of the Elkhorn Range, at elevations of from 6,000 to 8,000 feet. This range here rises very abruptly from Powder River Valley, presenting an imposing slope which in 5 miles gains 5,000 feet in elevation. The road enters the range at the mouth of Pine Creek Canyon, which heads at the rocky, dark precipices of Deer Creek Butte and Elkhorn Peak. One mile farther up the road turns and ascends to the headwaters of Elkhorn Gulch, a tributary entering from the north side. North of this gulch is a long, high salient, prominently visible from the valley and commonly called "Old Elk Mountain." This divides the drainage of Pine Creek from that of Rock Creek, incised far back into the heart of the range. A trail leads up Elkhorn Gulch and crosses the Rock Creek divide at a gap the elevation of which is 8,250 feet.

GEOLOGY.

The contact between the granodiorite of the northern and the argillite of the southern part of the Elkhorn Range crosses this mining district from east to west. At the mouth of Pine Creek Canyon black massive argillite crops. Half a mile higher up the rock becomes more crystalline, indicating proximity to granitic masses. Still higher up on the Elkhorn road contorted stratification is visible in the dark-colored siliceous argillite. The actual contact is not well exposed along the road, but runs up the gulch a short distance from the Baisley mine. West of this mine it follows the gulch pretty closely and crosses the Rock Creek divide 100 feet south of the United States mineral monument. The metamorphic rocks are here imperfectly slaty, the schistosity striking east to west, parallel to the contact. For the first 50 feet the rock is a fine-grained brownish hornfels; then dark argillite appears with contorted bands of siliceous cherty rock. Dikes of fine-grained diorite occur in the sedimentary rock 400 feet from the actual contact. Loose fragments of a crystalline limestone were noted 200 feet from the same place. An ill-defined mass of contact-metamorphic argillite was noted between the Hurdy Gurdy and the Baisley mines, contained in diorite.

The granitic rock near the contact is a diorite of medium grain, sometimes even becoming fine grained very close to the same. Northward from the contact quartz appears, the hornblende becomes less prominent, and the rock shades over into a granodiorite. Locally, as in the Baisley shaft, the diorite develops as a coarse hornblende rock.

The Pleistocene glaciation of the Elkhorn Range is well marked along Pine Creek. A broad débris fan extends over the valley from the mouth of Pine Creek Canyon, which is about 1,000 feet higher than Powder River. Though a few bowlders are scattered over this alluvial cone, there is no good evidence that the glacier reached the valley. But immediately above the narrow entrance of the canyon morainal material is abundant. About one-half mile farther up is a well-defined terminal moraine, and all along above this point the broad bottom is well filled with glacial débris. A partly eroded stratum of white kaolin, an almost impalpably fine powder, covers the bottom of the canyon in places.

QUARTZ VEINS.

The veins of the Elkhorn district contain chiefly gold in an ore rich in sulphurets. About a quarter of the total tenor is usually amenable to amalgamation. Pyrite and zinc blende, with some chalcopyrite, are the principal minerals. The strike of the vein system is northeast to southwest, but individual veins can rarely be traced far. Most of them are contained in diorite, and the mineral belt seems to follow the contact of diorite and argillite. The total production is probably a little above $1,000,000.

Baisley-Elkhorn mine.—At present this mine is the most promising producer in the district. It is located high up on Elkhorn Gulch, a tributary of Pine Creek, the elevation at the mine being 6,700 feet. Its discovery dates from about 1882. Up to 1889 the ore was worked in arrastre; in that year the present mill was erected, consisting of 2 Bryan mills with plates, 6 percussion tables, 4 vanners, and a canvas plant. In 1897, the present owners, the Eastern Oregon Gold Mining Company, bought the mine for $60,000, since which time it has been in constant operation. Data in the Mint reports give isolated figures in regard to production: In 1889, $3,744; in 1891, $89,373; in 1892, $16,500. The total yield up to 1896 is given by Mr. Whittaker, the superintendent, as $535,000. During the last two years the production has been large, attaining from January 1 to August 1, 1900, $94,000.

The developments consist of a 700-foot crosscut to the vein, with drifts for 700 feet south and several hundred feet north. The ore above tunnel level was stoped out before 1897. Two hundred feet south of the crosscut a shaft was sunk on the vein to a depth of 180 feet, and sinking below that level is now in progress. Drifts on two levels in the shaft aggregate over 1,500 feet, the principal developments being on the south side of the shaft.

The country rock is chiefly a normal, granular hornblende-biotite-diorite of dark color. The contact with the somewhat crystalline and contact-metamorphosed argillite is only a few hundred feet distant to the southeast, the black massive croppings of the latter being visible across the creek. On the 180-foot level, 700 feet south of the shaft, the vein, which otherwise is entirely contained in diorite, gives sign of splitting up into stringers, and a black, fine-grained hornfels appears, which is simply an argillite altered by the heat of the diorite cooling close by it. Whether this is the main mass or simply a fragment of argillite inclosed in the diorite is difficult to say. At any rate the main argillite area is not far away.

The gangue is normal vein quartz with some calcite. In general character the ore is soft and rich in sulphurets, concentrating in the proportion of 7:1. The sulphides in order of their abundance are pyrite, black zinc blende, galena, and chalcopyrite, all of which occur in irregular intergrowth with the gangue, the pyrite alone being sometimes crystallized. Ruby silver is occasionally found. The chief value of the ore is in gold, which is partly—up to 25 per cent—free amalgamating, occurring in the pyrite or intergrown with black zinc blende and calcite in form of pale-yellow wires. Some of the brown zinc blende contains 160 ounces silver per ton and no gold, while some of the mentioned black blende contains much gold and no silver. The bullion is 700 to 750 fine. The concentrates are shipped to Northport, Wash., freight and charges aggregating $10 per ton. Their ordinary value is said to be $50 per ton, though richer batches are often sent. They contain from 2 to 4 ounces gold and from 10 to 20 ounces silver per ton. The richest ore is hand sorted and shipped; it contains values from 4 to 6.5 ounces gold and from 14 to 21 ounces silver per ton. Along with the ore is found some diorite converted to a white mass of sericite, calcite, and with small crystals of pyrite. This metasomatic product as a rule contains no pay.

The vein, which is traceable only through two claims, Baisley and Robbins-Elkhorn, has very inconspicuous croppings. The strike is northeasterly, the dip nearly vertical. The vein matter is confined between two well-defined walls, covered with polished gouge, but within these there are often subordinate fissures. Striations dipping 20° to 40° NE. were observed on the walls. Sometimes the whole width of the vein is an altered diorite of small assay value. In the payshoot the width is from 2 to 10 feet, many gradually fading seams running out on the north side. The ore streak in this width is a soft mixture of coarse sulphides with much crushed diorite and occasional streaks of quartz which may show comb structure; in one place a 2-foot ore streak was adjoined by 10 inches of white, barren quartz.

The pay shoot is rather irregular, but on the whole confined to the southwest end of the claim.

Other mines and prospects.—The Robbins-Elkhorn mine is situated near the Baisley-Elkhorn and covers the southeastern extension of the latter vein. It is not worked at present, but has been a notable producer. The developments consist of a 300-foot crosscut and 1,100 feet of drift. A production of $300,000 is reported, the ore being identical with that of the Baisley mine, and its pay shoot, in the northeast end of the claim, an extension of that of its neighbor. From all accounts it is a promising mine, but for some reason has been permitted to lie idle.

One thousand feet higher up in the gulch and northwest of the Baisley is the Hurdy Gurdy. Located in 1883, earlier than the Baisley, it was worked from 1887 to 1892, and is reported to have produced $80,000. Three carloads were shipped, the rest of the ore being milled in a small Tremain mill. It was opened by a crosscut 378 feet long. The vein is a small one, 20 to 24 inches wide and carries oxidized free-milling ore in diorite.

The Denny group is located near the head of the gulch west of the Baisley-Elkhorn and on the trail leading over to Rock Creek. The Elkhorn Bonanza is supposed to be located on the northeasterly extension of the Baisley-Elkhorn and has been extensively prospected by 3,000 feet of workings.

Rock Creek district.—At the head of Rock Creek about 2 miles due west of the Baisley-Elkhorn mine is a promising district, which, however, was not visited. A trail leads west from the Elkhorn mines to a gap (elevation 8,250 feet), from which a fine view is obtained over upper Rock Creek. The contact of diorite and granite is close by this gap, and it is clearly seen to cross Rock Creek near the Chloride mine and ascend the mountains on the north side. In a general way the veins are near the contact, though they are not parallel to it, and from this prominent place there is noted a series of prospects which follow the contact to the divide between the Middle Fork of Rock Creek and Cracker Creek, a tributary to Powder River. The Maxwell mine, owned by the Pierce Mining Company, covers 11 claims, and has been worked extensively through several tunnel levels for ten or twelve years. It has 4,000 feet of development work, but owing to litigation is not producing at present. A 10-stamp mill is built at an elevation of 6,600 feet, 1,000 feet below the croppings which appear in diorite near the gap mentioned above, but which lower down seem to cut across into the argillite. The strike is northeasterly, the ore similar to that of Baisley-Elkhorn, but carries more silver.

The Chloride mine is located on Rock Creek at an elevation of 5,900 feet. A considerable amount of work has been done on this property, the ore of which contains a great deal of silver, largely in tetrahedrite.

POCAHONTAS, AUBURN, AND MINERSVILLE DISTRICTS.

GENERAL FEATURES.

These three districts, occupying the southern end of Elkhorn Range, are best described together. From the culminating point of Deer Creek Butte (elevation 9,100 feet) the range continues as a narrow backbone for 7 miles southeasterly, until near Auburn a sudden descent occurs. The flanks of the range are 4 to 5 miles wide and present narrow, gradually sloping ridges separated by deeply incised gulches; on the east it sinks below Powder River Valley, 3,500 feet above the sea, while its western base is covered by the gravels of Sumpter Valley at an elevation of 4,000 feet. The foot of the southern end of the range is flooded by basaltic lavas up to an elevation of 4,500 feet and Powder River surrounds it in a semicircle; its canyon, south of Auburn, has not yet cut through the lavas, so that it is evident that before the eruptions the southern slope was more prominent than at present.

Heavy timber covers the middle slopes of the range, while the upper ridges and peaks are often bare and rocky. Southeast and east of Auburn the rolling foothills covered by lava and gravel support no forests.

GEOLOGY.

The two principal terranes which build up the southern end of the Elkhorn Range are a sedimentary series of dark-gray argillite and a dioritic rock intrusive in the former. The argillites predominate, but no detailed mapping was made of the two formations.

The age of the argillite is in doubt, as no fossils have been found, but it is believed that they are older than the Triassic series of the Eagle Creek Mountains. As, on the other hand, the strata are continuous with those of Sumpter and Bonanza in which imperfect fossils have been found, they must be post-Algonkian and are most probably of Carboniferous age. The strike and dip are often very difficult to ascertain, as most of the heavy strata consists of massive siliceous argillite without schistosity or bedding. The prevailing strike of the bedding, conforming with the structure of the whole region, is N. 70° to 80° W. and the dip 60° S.

On Marble Creek, at an elevation of 5,400 feet, is a large limestone mass embedded in the black siliceous argillite, and rising as a steep wall 300 feet above the gulch. At Pocahontas, in the foothills, the rock is very much decomposed, but on the tunnel dumps there is black fissile argillite with small lenses of limestone and sometimes sharply defined cubes of pyrite. At the mouth of Salmon Creek, one-half mile above the Nelson placers, a greenish-gray massive rock crops, showing on weathered surface outlines of fragments of probably volcanic rocks; this is evidently a tuffaceous argillite. In Washington Gulch, Griffins

Gulch, and Elk Creek, black, siliceous, sometimes cherry, argillites prevail, but contain interstratified some calcareous rocks, as well as some fissile slates.

At Auburn the series is more markedly stratified, striking N. 70° W. and dipping 60° S. A jointing, striking northeasterly and dipping 70° NW. was also noted. The rocks consist of alternating, siliceous, and fissile argillite, the former often in lenses and curved streaks. Occasionally small masses of limestone occur.

At Minersville a similar formation is shown. The rounded foothills occupied by this formation are deeply decomposed and the surface is covered with small fragments of chert or siliceous argillite.

The intrusive rock mentioned above is a light to dark greenish-gray diorite, sometimes approaching a gabbro, of medium to fine grain. Nearly always this rock is also irregularly crushed and traversed by small white seams, and is, in fact, identical with the diorite and the gabbro of the Virtue district. It is very different from the fresh and massive diorite and granodiorite of the northern part of the range and is certainly older, having participated in some of the mountain-building movements. Heavy masses of this crop on Goodrich Creek, on Marble Creek below and above the limestone, high up on Salmon Creek, and finally in the high range above Minersville. The rock is clearly intrusive in the argillite formation.

Traces of glaciers are found in most of the gulches heading close to the main range, but nowhere did they reach the valley, and none of them approached the Pine Creek glacier in size (see Elkhorn district).

The origin and structure of this range offer many as yet unsolved problems. We can not doubt that its great features were carved out long before the Miocene lavas flooded its southern foot, although many modifications in its form and structure have occurred since then. The bold front of the range facing Powder River Valley suggests an old fault line, emphasized by comparatively recent orographic movement. That such a fault plane really exists and that movements have taken place on it in Pleistocene time will be shown in the description of the Nelson placers. This direct evidence is of the highest importance, and in the light of it Powder River Valley appears as an area of recent subsidence.

GOLD-QUARTZ VEINS.

Though, as will be shown below, nearly every creek and gulch heading in this part of the range has carried more or less placer gold and a few have been enormously rich, there is throughout a very marked absence of important vein systems to which the origin of these placers could be attributed. In part this may be due to insufficient prospecting, but in most cases I believe that the placer gold was here rather derived from small seams and veinlets than from prominent fissure veins.

A few prospects have been discovered on Pine Creek and on Goodrich Creek. At the limestone mass on Marble Creek the black argillite contains some auriferous pyrite; but no mines of importance are found until the Pocahontas district is reached, in the foothills between Marble and Salmon creeks. Discovered in early days, it is mentioned in Raymond's report for 1872 and has been intermittently worked, in a small way, since then, the total production exceeding $100,000.

The veins strike nearly north and south and dip 20° to 35° W. They are 1 to 3 feet wide, the vein matter consisting of clay with streaks of white quartz. The gold is very high grade, being worth $18 to $19 per ounce, and said to be free milling. The country rock is a very decomposed calcareous argillite. Of the different veins the Tom Paine has been the principal producer, one small chimney producing $70,000 of coarse gold about eighteen years ago. It has been developed by several tunnels, the lowest, in Nelson Gulch, having an elevation of 4,200 feet. This tunnel is 225 feet below the croppings. A winze 60 feet deep was sunk in it. No work is done on the claim at present. The quartz is reported of sugary texture, mixed with clay. Some adjoining claims, notably the Old Soldier, were prospected in 1900. The Old Soldier is on the east side of the Tom Paine, and shows in several inclines and tunnels as a 1 to 2 foot vein of clay with streaks of quartz. Some of this ore was worked, with reported good results, in an arrastre erected in Salmon Creek.

In spite of the rich placers of Salmon Creek, no quartz veins of any importance have been located on it. In the exposed bed rock of Nelson's placers many veins are exposed which strike northeast and have a steep dip; from 1 to 2 feet wide, these veins consist of soft, crushed rock with little stringers of quartz, all of which are said to contain gold, though usually only a very small amount. Veins of this type are probably the source of the placer gold.

A few quartz prospects are located on Washington, Griffin, and Elk gulches, but have not been developed. Three miles west of Baker City, in the lowest foothills, is the Big Buffalo claim, opened by a 300-foot crosscut, and showing a mass of black argillite traversed by seams of quartz, calcite, and a little pyrite.

At Auburn several quartz claims are located north and northeast of the settlement. They have been known since early days and are mentioned in the early Raymond reports. Most of them appear to be small seams rather than well-defined veins. All of these seams, however, are said to carry gold.

At Minersville prospecting for quartz has proceeded actively during the last year. Several narrow mineralized streaks in black slate have been opened by short tunnels, and from higher up on the range a 2-foot vein of quartz with chalcopyrite is reported.

PLACER MINES.

Nearly every gulch of the south end of Elkhorn Range has been worked on a more or less extensive scale for placer gold, though few localities have been exceedingly rich. Though the bulk of the gold was extracted shortly after the discovery, in 1862, some work is yet going on at several of the old diggings, showing that the gravels are not yet exhausted.

At the northern end of the eastern slope small placers have been worked on Marble Creek, near the limekiln. On Salmon Creek the placers are of much greater importance. This creek was worked with success for about one mile upward from the mouth of the canyon. The gravels were 4 to 10 feet deep and covered by 10 to 15 feet of an exceedingly fine, brilliantly white kaolinic material. The bottom of the canyon was originally filled with deposits to a width of one or two hundred feet. Working downstream, the placer miners at the mouth of the canyon gradually discovered a very remarkable deposit, called the Nelson placers. These have been worked successfully for thirty years by the hydraulic process, and are by no means yet exhausted. The working season extends from April to September, 1,000 miner's inches of water being used. The yearly production has generally been from $20,000 to $30,000. In the Mint reports for 1889 the production is given as $77,000; in 1890, $19,000. The total production is believed to be over $400,000. For one period of six years the production is said to have reached $214,000. As the available grade is small, it is proposed to use a hydraulic elevator for mining below the level of the permanent sluice.

The mouth of Salmon Creek Canyon is marked by a low spreading débris fan. The Nelson placers are working the gravels of this fan in a pit covering 40 to 50 acres and from 20 to 100 feet deep. At the top of the bank the elevation is 3,750 feet. The gravel is subangular, many fragments reaching 1 foot in diameter, and consists of argillite and diorite, very little quartz being present. There are two layers. The upper stratum has a bluish-gray color, is 10 to 20 feet thick, and contains, evenly distributed, most of the gold. The lower stratum is yellowish-brown and its rocks are more decomposed. This also contains gold, though in lesser amount, and its bottom has never been reached. Covering the top layer, near the mouth of the canyon, is the same white kaolin which covers the gravels of the creek. The gold, which is worth only $14 to $16 per ounce, is ordinarily fine, though nuggets up to $10 in value occur. To the rough pieces quartz sometimes adheres.

Most interesting are the relations immediately at the mouth of the canyon, for here the hydraulic work has disclosed the presence of a continuous fault scarp 100 feet high and dipping 40° E. It is smooth now, but when first exposed it is said to have been almost polished and in places covered with a clayey gouge. The direction is northwesterly, but with occasional bends and bulges. The exposed fault line extends completely across Salmon Creek for a distance of 1,500 feet, and the same line, less well exposed, is seen in the Baisley diggings, one-fourth of a mile northward, and in the Carpenter placers, half a mile southeasterly.

A shaft has been sunk in the bottom of the hydraulic pit near the foot of the scarp, but no bed rock was found at a depth of 90 feet. A minimum vertical throw of 200 feet is here shown, the valley side having sunk relatively to the mountains (fig. 80). The upper blue gravel probably was accumulated during the Glacial epoch, while the lower dark-brown gravel is more likely to antedate that time; whether any very recent movement has taken place could not be decided.

Small placers have been worked in Washington Gulch, and the same applies to Griffin Creek and Elk Creek. The Griffin Creek placers are the oldest in eastern Oregon, having been discovered in the fall of 1861.

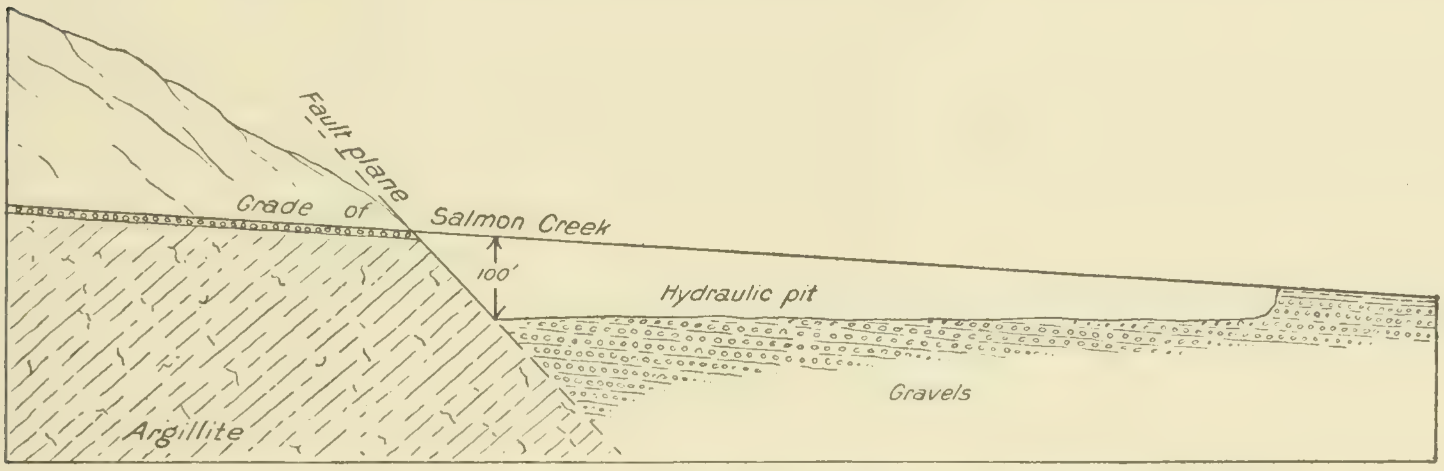


FIG. 80.—Section of Nelson placer mine, showing fault at foot of Elkhorn Range.

The workings are 6 miles southwest of Baker City and at an elevation of 4,750 feet above where the creek enters the lava hills. Some work was in progress in 1900. On the divide between Griffin and Washington creeks is a small area of high gravels which is said to contain gold in paying amount.

Most important were the placers of Auburn, in Blue Canyon, a tributary of Powder River. The diggings were discovered in 1862, and in a short time a town of several thousand inhabitants had grown up. For many years Auburn was the most prominent place in eastern Oregon; but the gold yield gradually diminished and the camp was given over to the Chinese. At the present time hydraulic mining is carried on by two or three white companies. The total production of Auburn is difficult to determine, but it did not nearly reach that of Canyon and the richest placers were soon exhausted. A small and rather steady production is maintained. The Mint reports give $12,000 for 1889, $2,600 for 1890, $8,900 for 1891, $3,000 for 1892. The important Auburn ditch was completed in 1863. It takes water from the head of Pine Creek and other water courses and carries it down to Auburn, a distance of over 30 miles; its capacity is 1,000 miner's inches.

Auburn is located in a wide basin-like valley at an elevation of about 4,000 feet. The argillites of the mountains here dip below the lava floods of the foothills. On both sides of the town the lava reaches up to elevations of 4,500 feet. The lavas cover soft, clayey, and loamy lake beds containing some coaly layers and impressions of deciduous leaves. On top of the eroded lake beds in the wide gulch rest subangular gravels 8 to 15 feet thick; the latter have been washed both in the gulches and on the flats. Near the town the depth to bed rock is not great; but farther down the valley the thickness of the sediments increases rapidly. The gravels are thus later than the lavas and have accumulated during the erosion of the present valley.

West of Auburn, on the road to Sumpter, several gulches with old placers are passed, Poker Gulch and California Gulch being next to Blue Canyon.

The deposits next in importance are found at Minersville, situated at an elevation of 4,300 feet on one of the small tributaries of Deer Creek. This is also an old placer camp, though not as rich as Auburn. Nearly all of the creeks flowing into Deer Creek from the east have yielded more or less placer gold. Miners Creek is worked at present on a small scale at the point where the stream leaves the old rock and enters the gravel deposits of Sumpter Valley. The gravel is coarse, with many heavy bowlders, and the gold is likewise coarse. Three short gulches southeast of Minersville, heading only 600 feet higher than the town, have been worked all the way up, and the gold contained in them is evidently of very local origin. In spite of this the gulches contain but little quartz.

SUMPTER AND CRACKER CREEK DISTRICTS.

GENERAL FEATURES.

The area described under this heading practically includes the upper Powder River Valley. South of Baker City Powder River cuts through the basaltic plateau at the southern end of the Elkhorn Range in a wide semicircle, and for about 12 miles flows in a narrow canyon. Going up the river, the canyon opens, at an elevation of 4,000 feet, into the wide Sumpter Valley, an alluvial bottom flanked by broad, gently sloping, forested benches. Beyond these the snowy summits of the Elkhorn Range rise abruptly eastward, while toward the west a heavily timbered ridge, of moderate elevation, separates the valley from the Burnt River drainage basin. A little above Sumpter a canyon again begins. The river forks into Silver Creek, Cracker Creek, and McCullys Fork, all heading among the high ridges leading to Elkhorn Range or Mount Baldy.

GEOLOGY.

The older rocks are very similar to those of the Elkhorn Range; there is no geological break between that range and the country west of it. The predominant rocks are argillites, cropping in the canyon below the Sumpter Valley, near the Burnt River summit south of McEwen's, at Minersville, all along the Elkhorn Range, and, finally, above Sumpter until the contact with the Bald Mountain area of granodiorite is reached. The argillites appear in great variety. Some of them are black and fairly fissile, forming almost normal clay slates; another and very common variety shows little stratification and is a dark-brown to black, dense, fine-grained rock, containing more silica than the ordinary clay slates. The siliceous argillite is often interbedded with the clay slate as nodules and lenses, sometimes contorted and elongated. Transitions into black or gray chert are also common. Occasionally the argillites are calcareous, but limestones are not abundant. One limestone lens crops about half a mile north of Sumpter in a low saddle, but it is not very large and is not traceable far. Interbedded fine-grained greenstones and their tuffs were noted at several places, though on the whole the series does not contain much volcanic material. Extremely altered tuffs appear on the road leading to Clifford, and also on the lower part of McCully Fork. The stratification is more clearly marked than in the Elkhorn Range. The whole series strikes east to west or a few degrees north of west. The dip is steadily southward at angles of 45° to 80°. In places a schistosity, or jointing, striking northward and dipping steeply westward, is noted. There is rarely a strong fissility developed parallel to the original dip.

The age of this argillite formation is in doubt, as no fossils of any kind have been found. Not unlikely the rocks may be of Carboniferous age; and if so, they would occupy a position very similar to that of the Calaveras formation in the gold belt of California.

Few dikes or intrusive masses are found south of the great area of granodiorite of Bald Mountain. Near Bourne small dikes of aplitic rock have been noted. Between Sumpter and Cracker Creek two dikes of very much altered igneous rock were noted crossing the road, one below and the other above Halfway House. Both were probably originally diorite-porphyries, but they now contain so much sericite, calcite, and pyrite that their original character is obscured. One of them is accompanied by small quartz veins, and doubtless contains a little gold. Similar extremely sericitized dikes were observed in the Golconda and the Columbia mines.

The general course of the upper Powder River was evidently laid out before the Neocene outbursts of Columbia River lava began. Great basaltic eruptions flooded the valley south of Baker City to a height still clearly indicated by the flat dissected tables above the river. By these flows the upper river was dammed to a height of 4,600 to 4,700 feet above the sea, and this barrier created Sumpter Valley. Accumulations of coarse gravels at once began and filled the valley to an elevation of 4,600 feet, and these old gravels may still be seen leaning against the older rocks—at Sumpter and Minersville, for instance. As the lava barrier was gradually cut through, lower terraces were developed. These gravel flats must be considered of late Neocene (Pliocene) age. At present the river has cut down to a depth of 700 feet below the top of the lava flows at the lower end of Sumpter Valley. The alluvial flats which follow the river should be referred to the Pleistocene period.

PLACER DEPOSITS.

The Sumpter placer mines were discovered in 1862, and have been worked more or less actively since that time. The first area of placers begins a short distance below Sumpter and extends up to the point where the Cracker Creek vein system cuts across the creek. Another mining district, the placers of which are mentioned under the heading "Minersville district," is situated on Deer Creek a few miles east of Sumpter. Several of the smaller creeks north of Minersville draining the western side of the Elkhorn Range and emptying into Deer Creek also contain placer gold. Placers have also been worked in several gulches above Sumpter and tributary to Powder River, such as Buck Gulch, Mammoth Gulch, and others.

The mining has been done largely by Chinese companies, and it is not believed that the diggings were very rich, compared with those of Auburn, Canyon, Mormon Basin, and similar places. It is impossible to ascertain the total output. At present the bench gravels are worked only in two places adjoining Sumpter—the Downie and Ellis mines. The annual yield of the Sumpter placers probably varies from $10,000 to $20,000. The present river bed, from 50 to 300 feet wide, and the low bars were worked during early days for a few miles above Sumpter, but the diggings are now abandoned. A short distance below Sumpter the gravels in the present bed contain fairly coarse gold, it is claimed, and the possibility of dredging has been suggested, though the depth is far too great to reach bed rock by such machinery. More detailed tests must decide whether this is possible.

The gravels of most importance for present operations are the bench deposits, from 30 to 100 feet above the stream channel. These deposits connect directly with the Pliocene gravels skirting the base of the hills all around Sumpter Valley. Near Sumpter the auriferous veins above have enriched them sufficiently to make them available for placer work. Between Sumpter and McEwen's many shallow gulches cut in these gravels have been profitably mined. Sumpter itself stands on these bench gravels, which have a depth of 15 feet or more. At the electric-light plant a shaft was sunk 80 feet through sandy strata with two streaks of gravel which prospected well. Bed rock was not reached. The old channel probably underlies the bench gravels on the northeast side of the river, and from all indications it had a steeper grade than the present river. Most of the bench gravels lie on the narrow point opposite the town, between Cracker Creek and McCully Fork, on which the gravels reach a height 60 feet above the stream. The junction of two forks is here evident. The Pliocene equivalent of Cracker Creek is covered by the 200 acres of the Ellis mine, the principal workings of which are north of the Granite road where it crosses the gravel point. Several acres have here been hydraulicked, the banks being up to 80 feet high. The well-washed gravels, fairly coarse, contain the rocks which crop above. The gold occurs in medium fine particles and the yield is reported as up to 16 cents per cubic yard. The bed rock is not exposed until a few hundred yards above Sumpter, where the large gravel areas dwindle into small benches lining the banks of Cracker Creek. A considerable amount of gravel remains, though much of it is not accessible without elevators, on account of lack of grade. The water is supplied by ditches aggregating 10 miles and carrying 1,000 miner's inches. In past years these diggings have been leased to Chinese companies.

The Downie placer mines, 1½ miles from Sumpter, are working on gravels representing the Pliocene McCully Fork, and comprise about 140 acres. The Downie channel is higher than the one just described, and forms a distinct depression on the east side of the creek. The trough is 200 feet wide and contains well-washed gravel 50 feet deep. The bed rock is 40 feet above the present creek. Going downstream, the bed rock descends rapidly, and where the Granite road crosses the point between the forks, mentioned above, no bed rock is seen. The mines dispose of a good supply of water from 6 miles of ditches, carrying 1,000 miner's inches. Operations can be carried on until late in the fall. Two giants are usually operated by Chinese leasers, and the annual yield is reported to be about $9,000.

Rich placers with coarse gold are located in Buck Gulch, a tributary to McCully Fork, near the Granite road and 4½ miles from Sumpter. Scarcity of water restricts the operations.

LIMESTONE AND IRON ORES.

An outcrop of crystalline limestone of good quality occurs in the argillite half a mile north of Sumpter. It could not be traced far either way in the direction of the strike of the rocks, but it may be continuous for a greater distance than is apparent, as the rocks on the hillside are not well exposed. The outcrop is 10 to 15 feet across, and a small quantity has been quarried for the smelter which was in operation for a short time during 1900.

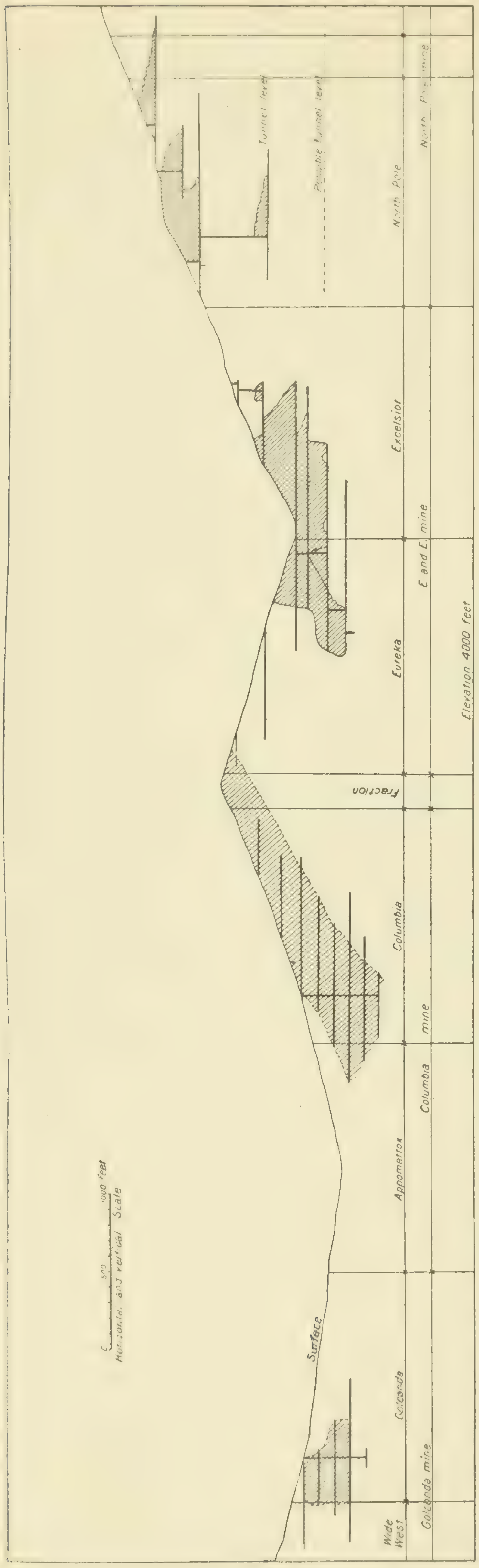


FIG. 81.—Vertical section following the vein from the North Pole mine to the Golconda mine. From data by Emil Melzer. Shaded areas indicate stoped ground. For Columbia and Golconda mines the data are only approximately correct.

A mass of hematite of no great extent has been found in the argillite on the Burnt River divide, 5 miles south of Sumpter. Three miles southwest of Sumpter a small deposit of a black earthy manganese ore occurs. It is near the Bonanza trail, also on the Burnt River divide. It was used in the smelting operations as a substitute for iron.

QUARTZ VEINS IN GENERAL.

Many small veins and indications of mineralization are found near Sumpter, but the big vein systems occur 7 miles above this place. There is practically one continuous vein system, beginning at the Baisley-Elkhorn mine and continuing across to Cracker Creek, with a strike varying from east-west to northwest-southeast, and some of the most important mines in eastern Oregon are comprised in it. The part of the vein system tributary to Sumpter begins at the North Pole mine and continues westward through the E. and E., Columbia, Golconda, Amazon, and Bunker Hill mines. In this distance of 5 miles the vein continues strong and unbroken, but gradually changes its strike from northeast-southwest to east-west. The country rock is, throughout, argillite, and the vein is of the composite type; that is, it is found as a wide, shattered zone, though ordinarily with well-defined walls. The gangue is quartz throughout, containing gold and sulphurets. The width is from 5 to 100 feet. It is easily the most strongly defined and persistent vein in the Blue Mountains.

A short distance northward is the Ibex vein, which is continuous for at least 3 miles and is nearly parallel to the North Pole vein. It resembles the latter greatly, except that it is usually narrower. There are many other smaller veins and branches thrown off from the two large veins.

The veins of Sumpter were known as far back as 1870, but active exploitation was not attempted until about twenty years ago. The earliest mill was erected on the Mammoth claim about this time.

North Pole mine.—The most northeasterly of the important mines on the big vein comprises two full claims, the North Pole and the More-or-Less. It is located on the mountain slope northeast of Cracker Creek, and ascends to a height of 2,000 feet or more above that stream. The extent and workings will be seen from fig. 81. The elevation of the lowest tunnel is about 5,800 feet. The North Pole claim was located in 1887, croppings of rich ore being found near the surface. The following year the claim was sold to A. Baring, of London, for a reported price of $10,000. The adjoining claim and fraction was acquired for $14,000 in 1897. Though operated since 1887, the most active work on the property has been prosecuted since 1895. The total production is not known, but during the last four years 13,400 tons have been treated, the assay value of which approximated $15 per ton.

The mine is equipped with a cyanide plant provided with two Bruckner roasters, which have a daily capacity of 20 tons. This plant works the zone of semioxidized ores only, and in spite of fine crushing to 1 mm. by ball mills, it is necessary to roast the ore very slowly and carefully. The cyaniding is done in 50-ton tanks, percolation lasting fifteen to twenty days. The extraction by cyanide is stated by Mr. Melzer to be 84.9 per cent of the assay value. For purposes of working the unoxidized ore a 10-stamp mill and a Huntington mill with concentrators have recently been added, making a total capacity of 80 tons per day.

The North Pole is developed by means of three main tunnels, shown on fig. 81, the upper two starting on the vein, the lower one being a crosscut for 1,000 feet. The upper tunnels are, respectively, 450 and 750 feet above the main adit, the total vertical distance on the vein opened by the workings being 850 feet.

Throughout the mine the country rock is the normal, black, hard, siliceous argillite, without clearly visible stratification. In the long crosscut a jointing shows in several directions, the most prominent being flat or dipping gently east or west. There is no jointing or parting parallel to the vein. The strike of the vein is N. 25° E., and its dip 70° to 80° SE. The croppings are distinct and in some places carry good values. On More-or-Less claim a large mass of quartz crops along the line of the vein, measuring almost 200 feet across. Where the main crosscut meets the vein the latter is 22 feet wide; in places it bulges out to 40 feet, and again contracts to 7 feet, but never thins out entirely. The walls are fairly well-defined fault planes, especially the foot wall. The vein matter is composed of rock of all gradations between crushed argillites seamed by quartz and pure white massive vein quartz. On the whole, there is a large amount of solid vein quartz extending for several feet across the vein and for long distances parallel to it. Other parts of the vein form an intimate mixture of quartz and small leafy or irregular inclusions of argillite, sometimes indistinctly defined from the quartz and giving the impression of a mass of argillite mud partly silicified and cemented by quartz. On the whole, there are no such large and sharply defined inclusions as mark the vein in the lower tunnel of the Columbia. Comb structure is frequently seen on a small scale, though most of the quartz is massive. The argillite in and just outside of the vein is often filled with coarse cubical pyrite of low assay value. Outside the pay shoots the quartz is white and barren of sulphides. The pay quartz is characterized by arsenopyrite, and also by pyrite in minute grains and slender crystals, rarely over 1 mm. in length. In the center of the pay shoots richer lenses are occasionally found, containing up to $150 per ton, and sometimes also a little native gold with tellurides rich in gold and silver. The ordinary ore rarely contains any sulphurets other than arsenopyrite and a little pyrite; sometimes also chalcopyrite. Native gold is seldom seen, though a little, about 6 per cent, may be caught on amalgamating plates. The chief value is in the sulphurets. The average sulphide ore contains 0.688 ounce of gold and 1.200 ounces of silver per ton, or a total average value of $14 per ton. The white quartz outside of the pay shoots carries only small values. Very frequently a peculiar arrangement of the sulphides is noted in the pay shoots. The quartz is here full of small curved and concentric streaks of arsenopyrite, in general not parallel to the walls and frequently sharply cut off. The detailed examination shows that this irregularly concentric structure is due to crustification, but that by subsequent motions the crustified mass has been broken and recemented, in places forming a real breccia (see Pl. LXVIII, *A*). The quartz is free from calcite, but the latter mineral occurs on all little secondary slips and fractures which brecciated the original crust. On these secondary fractures arsenopyrite is also found.

The pay does not include the whole width of the vein, but when present occupies a space of 2 feet up to a maximum of 12 feet, appearing along one wall or the other, or in the middle of the vein, adjoined by barren quartz on both sides. Usually the form is that of a number of lenses which sometimes overlap. The pay shoot, ordinarily on the foot wall, may break across in stringers and streaks and follow the hanging wall for a distance. It is stated that in general the pay has a tendency to follow the seams of gouge found in the vein. As a whole, it has a flat southwesterly dip, as in the Columbia and E. and E. mines, and may in fact be continuous with one of the E. and E. shoots. A large amount of ore is unquestionably in sight; thus, for instance, it is stated that there are 600,000 tons between the short intermediate and the uppermost tunnel level. Besides the pay shoot following the slope of the hill, there are others exposed in the lowest and middle tunnels.

A partial oxidation has taken place for a distance of 200 or 250 feet from the surface. The changes in values are, probably owing to the hardness of the quartz and the fineness of the sulphides, much less marked than is usual in gold veins. According to Mr. E. Melzer, the oxidized ore is but very little richer than the deep ore, though its physical condition has changed so that the same metallurgical processes are not applicable. Average assays of surface ore give 0.968 ounce of gold and 0.700 ounce of silver, or $20.40 per ton, while the sulphide ore assays 0.688 ounce gold and 1.2 ounces silver, or $14.40 per ton, the gold having thus increased slightly and the silver decreased during the process of oxidation.

Eureka and Excelsior mine.—The mine owned by the Eureka and Excelsior Consolidated Mining Company comprises the two claims on the North Pole vein having the above names, and is usually known as the E. and E. It was bought as a prospect in 1888, and from this time up to 1898 it has been worked. In 1900 it was idle and the underground works were not accessible. For most of the data regarding it I am indebted to Messrs. E. Melzer and J. Arthur, of Sumpter. A 20-stamp pan amalgamation mill was erected in 1889 for $200,000, which proved utterly unsuited to the ore, and for several years the mine was worked with indifferent success. The doubtless incomplete Mint reports give the production as $500 for 1889, nothing in 1890, $135,000 in 1891, and nothing in 1892. In 1895 the mine was leased to Mr. J. H. Longmaid for three and one-half years. The lessee put vanners in the mill, and in three years mined and milled 75,000 tons of ore, valued at $900,000. Since the expiration of the lease the property has been idle except for a little surface work, but it is said will soon be reopened. If worked in a rational manner the property will doubtless maintain its reputation as one of the best mines in Oregon.

The total production may be estimated as $800,000, the mine thus possessing the record production among the new mines in the Sumpter district.

The developments consist of between 7,000 and 8,000 feet. There are two small tunnels on the hill northeast of Cracker Creek, 200 and 350 feet above its bed; two tunnels on the southwest side of the water course; a main level at creek level, at an elevation of about 6,500 feet; a shaft 200 feet deep sunk from this tunnel; and still another shaft sunk 100 feet below the 200-foot level in the first shaft (fig. 81). The mining methods employed were crude and faulty, the evident plan being to extract as much as possible without regard to even the immediate future of the mine.

The country rock is the usual black, siliceous argillite. The vein, directly continuous with that of the North Pole on the northeast and the Columbia on the southwest, strikes N. 34° E. and dips 60° to 70° SE. The croppings are well defined, and the vein seems to have paid from the grass roots down for a distance along the surface of 1,300 feet. The vein appears to be identical in character with that of the adjoining claims, being a shattered zone in argillite, in some places as much as 30 feet wide. The milling ore carries pyrite and arsenopyrite in quartz similar to that of the North Pole. It rarely contains free gold. The concentrates amount to 8 to 10 per cent and assay from $100 to $200 in gold, with a little silver. The 70,000 tons of ore extracted by the lessee averaged $12 per ton by assay value. There was also a certain quantity of rich shipping ore yielding from $80 to $240 per ton. Some surface ore extracted in 1898 yielded $8 per ton.

There are four pay shoots in the mine, which may be said to partly connect, forming a body dipping southwest at a gentle angle, like the shoots of the North Pole and the Columbia. In fact, the shoot of the E. and E. may be considered as the continuation of that of the North Pole. Mr. Arthur says: "A surface tunnel on the Excelsior claim disclosed a shoot 200 feet long, the ore still remaining in the face and very likely continuing to the North Pole line, 400 feet distant. This shoot is 4 feet wide and contains $10 per ton in gold. The better-grade ore, assaying $50, was sorted and shipped. This high-grade ore appears as a streak 2 feet wide and 75 feet long in the bottom of the drift and adjoining the milling ore. The shoot next south of this was 400 feet in length and from 1 foot to 15 feet in width, differing from the first in having a wavy character, the thickness changing suddenly and often. The shoot, with an average width of 4 feet, has been mined down to a depth of 160 feet from the surface.

The shoot south of this is on the Eureka claim and is said to be 200 feet long and 4 feet wide. From these stopes came most of the shipping ore and a higher grade of milling ore, showing some free gold, not found in the other stopes. This shoot was mined out to the 260-foot level. There is another shoot still farther south which is imperfectly known, but from surface cuts and tunnels it should be 600 feet long and one-half foot in width, averaging from $5 up in gold."

While the deeper ore is fresh, that from the surface down to 100 feet below is more or less oxidized. Regarding the character of this oxidized ore see North Pole mine.

Columbia mine.—This mine is situated on Fruit Creek, at an elevation of about 5,600 feet, between the Golconda and the E. and E., and comprises two claims on the North Pole vein, called the Columbia and the Appomattox. It is owned by the Columbia Gold Mining Company, who also possess a number of other claims in the vicinity. The mine was sold to the present company in 1895 by Cable Brothers, but during the first few years there was but little gold produced. During the last three years the mine has been in active operation. The total production is not known, but is supposed to be in the vicinity of $300,000. There is a 10-stamp mill with six concentrators on the property, capable of crushing 28 tons per day. The tailings are saved, and during 1900 a cyanide plant was built to work them. Ten additional stamps are to be erected. Besides the milling ore, smaller rich chimneys are met with. This ore is shipped to smelters, one car of 20 tons containing about $1,000 per ton. The developments are extensive and comprise in all over 8,000 feet. There are three tunnels on the vein in the steep hill which rises 500 feet above the shaft house, the lowest being at the level of the latter. There is also a 500-foot vertical, 3-compartment shaft with five levels, from which drifts extend several hundred feet each way. Admittance below tunnel level was refused.

The country rock is the usual black argillite, rarely showing stratification or schistosity.

The surface croppings, which can be traced continuously from the E. and E., are very strong, showing a width of from 70 to 100 feet. The vein strikes nearly due northeast and has a southeasterly dip of 60°. Its general character is similar to that of the North Pole. It is a zone of fracture in the brittle siliceous argillites, with a width of about 40 feet, the walls being fairly well defined. Outside the walls there is no strong mineralization. The structure is well shown in the lower tunnel level. The zone consists of quartz, more or less completely filled with inclusions of argillite, from 3 feet in diameter down to the smallest fragment. These inclusions are cemented by normal, white vein quartz, clearly deposited in open fissures and sometimes showing drusy comb structure. The fragments are often so isolated by the quartz that though very abundant they could not have filled the space before the advent of the quartz. Still the quartz is certainly not derived from replacement, and often extends solid over spaces of several feet. This character of vein continues throughout the mine, I am informed, for a long distance, vertically and laterally, without closing down. The foot wall is smooth, hard, and extremely well defined. The hanging wall, though not so well marked, is formed of argillite impregnated with pyrite. The argillite contains pyrite, and has in places been somewhat silicified, and is sometimes filled with metasomatic sericite. Some doubtful rocks also occur which are probably altered diorite-porphyry, and now filled with pyrite, calcite, and sericite.

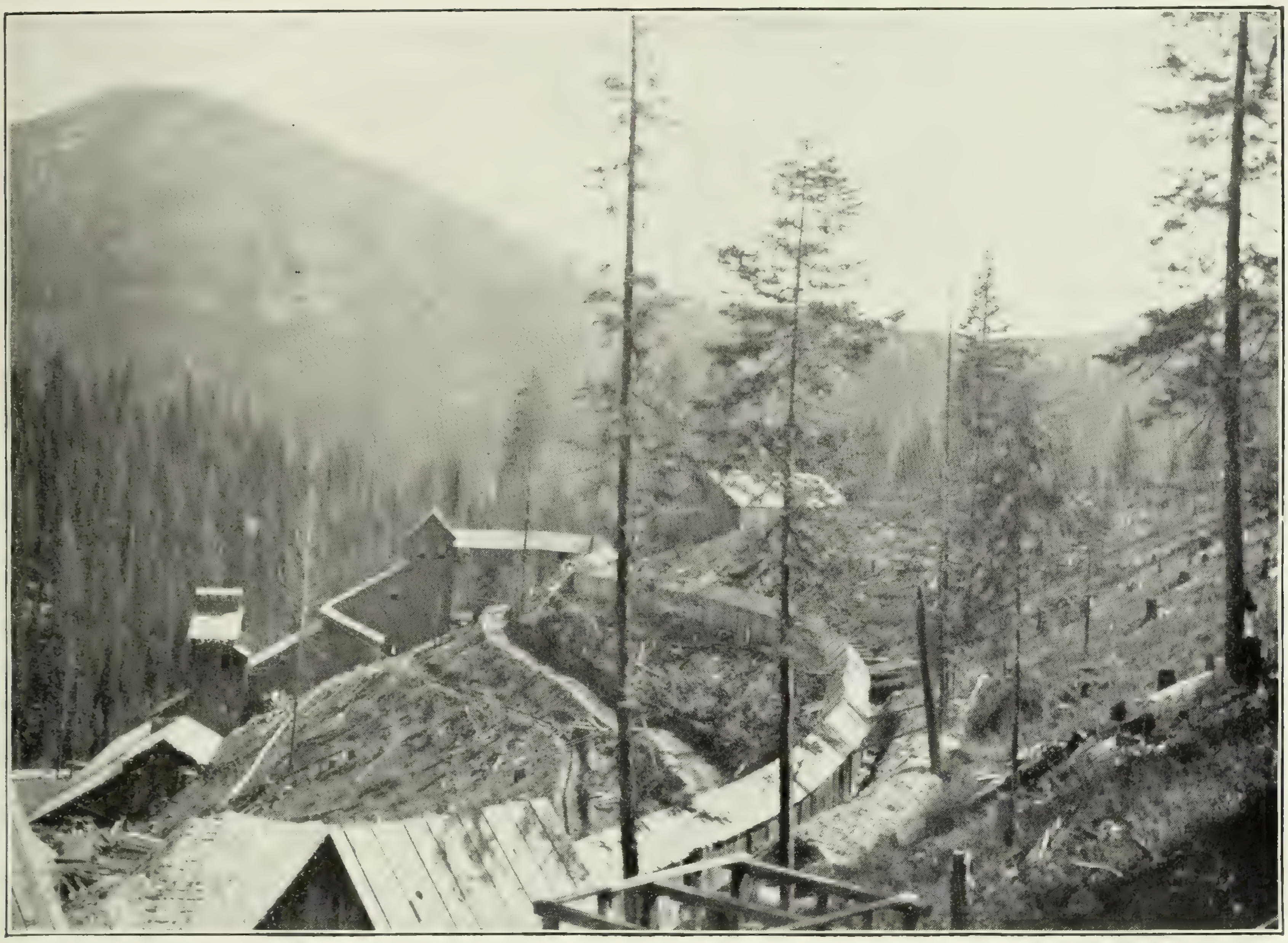
The ore consists of quartz carrying up to 8 per cent of sulphurets, chiefly pyrite and arsenopyrite, though the altered slate may also show fair tenor. The solid white "bull quartz" and the sugary quartz carry no values. The average value of the ore is $10 and over per ton, chiefly in gold. About 40 per cent of the gold is caught on the plates, the bullion containing 702 parts gold and 277 parts silver. The concentrates are rich, carrying from $100 to $175 per ton, of which a considerable proportion is silver (Au: Ag = 1:15, by weight). Occasionally some coarse gold is seen in the ore. Smaller chimneys furnish rich ore, which is shipped, often containing 11 ounces gold and 39 ounces silver, or about $250 per ton. This consists of fragments of sericitized argillite cemented by vein quartz and containing native gold and sulphides.

A number of interesting minerals occur on this vein. They comprise native gold, native copper (tunnel level), pyrite, arsenopyrite, zinc blende (rare), pyrargyrite, cinnabar, antimonite, chalcopyrite (sometimes several per cent in shipping ore), stibnite (tunnel level), also an unidentified telluride.

In the shipping ore there occurs also a black tetrahedrite with brown streak, which, upon examination by Dr. Hillebrand, proved to be a mercurial variety, or schwatzite, not previously known from the United States. Among gangue minerals are to be noted quartz, sericite, fuchsite or mariposite (in the rich ore), and also a little calcite. The latter mineral seems to be of very late introduction, traversing quartz and argillite in minute and irregular seams.

As will be seen from fig. 81, the pay shoot as a whole occupies the southwestern slope of the ridge between Fruit and Cracker creeks and dips about 20° SW. on the plane of the vein, similarly to the pay shoots of the North Pole and the E. and E. mines. It is believed that the shoot as a whole is continuous from the top of the ridge to the bottom of the shaft, thus extending over a vertical interval of 1,000 feet. Within this shoot are found smaller chimneys of very rich ore. The pay does not occupy the whole width of the vein, but appears in streaks from 2 to 4 feet in width, following either wall or crossing from one wall to another. On the tunnel level the principal shoot follows the footwall, but throws out three ore splits, one of which carries much free gold and cinnabar and finally crosses over to the hanging wall.

The ore worked at present from the shaft is not altered by surface influences. Above the tunnel level a partial oxidation appears and



A. GOLCONDA MINE AND MILL.

B RED BOY MINE.

the ore is no longer suitable for concentration, being apparently similar to the North Pole surface ore, which is roasted and cyanided. Much of this oxidized ore remains as yet untouched.

Golconda mine.—This part of the North Pole vein was located as the Golconda claim in 1887 and sold for a reported sum of $24,000 in 1897, there being at that time only 250 feet of development. The Golconda Mining Company at present owns, besides this claim, 8 others adjacent, which are said to cover 2 parallel veins. The Golconda and the Wide West are located on the North Pole vein. In 1898 a large bromination plant, of a capacity of 100 tons per day, was erected but soon found unsuited to the character of the ore. A 20-stamp mill and a Bryan roller mill, together with 18 concentrators, were substituted, giving a total capacity of over 100 tons per day. Crushing was begun in January, 1900, and the mine has consequently not as yet any great production to its credit. In the fall of 1899 a rich ore chimney was struck, 20 tons of which yielded $10,000 in the mill. Still richer ore was shipped to smelting works. In September, 1900, 15 stamps were running. At present there are 2,500 feet of developments, including a 400-foot double compartment perpendicular shaft and 4 levels, the opening of the fourth having just begun; also a 650-foot tunnel running southwest on the ledge.

The country rock is the usual black siliceous argillite, sometimes showing schistosity, but oftener massive. Occasionally this contains light-gray, very much altered dikes of an igneous rock which originally may have been a diorite-porphyry. The croppings of the main vein can be followed from the Columbia for at least part of the distance. A statement is made by some that there is a fault between the two mines; whether this is true is not certain; at any rate the vein holds its general direction well enough. The croppings are not very conspicuous except on the hill southwest from Golconda shaft, where they are marked by a very heavy mass of quartz similar to that above the North Pole. The outcrops carry low values throughout, rarely over $1 per ton.

The developments in the shaft have shown the existence of a very wide mass of crushed argillite. The general trend of this is northeast; the dips in the upper levels are northwesterly at steep angles, while on the fourth level this is reversed to a southeasterly dip, similar to that of the Columbia and the North Pole. In places this crushed zone is 200 feet wide and traversed by several seams, running across the vein in a northwest-southeast direction, on some of which quartz veins carrying gold appear. The principal pay shoots are found as streaks 2 to 4 feet wide in this shattered argillite and pursue a rather irregular course. The ore carries but little quartz and is largely a replacement of argillite and some porphyry by finely divided pyrite, marcasite, and arsenopyrite and a very little chalcopyrite and zinc blende. The average value is believed to be from $8 to $15 per ton. The ore is in part free milling, containing from 40 to 50 per cent of gold which can be caught on the plates. The sulphurets are stated to be of comparatively low value, the percentage contained in the ore being from 7 to 14.

On the second level the crushing and the irregularity seem to have reached a maximum. On the fourth level the lode contracts to less than 100 feet and the ultimate walls are fairly well defined. The whole mass between them consists of crushed argillite with replacing sulphides and traversed by small quartz veinlets. The pay streak is from 2 to 3 feet wide. It is to be expected that more regularity will be found in depth, and it may also be expected that there will be somewhat less free gold. The pay shoots in general follow the trend of the vein, but a very rich chimney, alluded to above, did not follow this rule. It occurred on the second level, cutting across the general direction of the vein and dipping 30° SE. The shoot was 70 feet long and 14 feet wide; it did not extend far above or below the level. Only a part of it was rich in native gold. The ore consisted of an argillite colored greenish by roscoelite and containing arsenopyrite and pyrite. The native gold, accompanied by tetrahedrite, occurred chiefly in little seams and fractures filled with normal vein quartz. The drifts and crosscuts on the four levels run very irregularly owing to the difficulty in following the pay shoot in such a wide crushed zone.

Mountain Belle mine.—This adjoins the Golconda property on the southwest and is located on the same vein, which here crosses Silver Creek. The Mountain Belle is as yet not a producing mine, but extensive prospecting has been done during the last two years. The vein is developed by a perpendicular shaft in the country rock 300 feet deep, with crosscuts and drifts from the levels. The shaft is located on the northeastern side of Silver Creek, 175 feet above the stream, and at an elevation of about 5,450 feet. The country rock is the usual siliceous argillite without clearly defined stratification. The vein, which shows on the surface in big outcrops of mixed quartz and argillite, strikes N. 60° E. and has, contrary to the ordinary direction for this vein, a northwesterly dip. As on the other properties on this vein, the character is that of a crushed zone between two usually clearly defined walls, the width of the zone being from 20 to 50 feet. The foot-wall half of the vein consists largely of crushed argillite cut in all directions by quartz veinlets, sometimes with comb structure. The quartz often contains minutely divided pyrite and arsenopyrite; the argillite is often filled with pyrite. The hanging-wall part is almost massive quartz, but full of little fragments of silicified and pyritic argillite. In other parts of the mine the whole vein is a quartz-seamed argillite. Again, the whole mass may consist of crumbly quartz. The values thus far developed are said to be low and much of the quartz is entirely barren.

Amazon, Analulu, and Bunker Hill claims.—The North Pole vein continues clearly marked across Silver Creek and through the above-mentioned claims. The Amazon has over 1,000 feet of tunnels on a vein said to be entirely similar to the Mountain Belle. On the Analulu also a considerable amount of development work has been done. On the Bunker Hill the vein shows quartz croppings of enormous extent; the developments here also exceed 1,000 feet, and the quartz is said to assay from $3 to $7 and over. Three claims, the Bunker Hill, Myrtle, and Lilac, are owned by a Canadian company. The vein where struck by the 300-foot crosscut is said to be 25 feet wide.

The great fracture, now traced for almost 4 miles, has gradually swung around from north-northeast to east-northeast. Beyond the claim last mentioned its continuation is not definitely known, but it is possible that it here splits into several branches. Already, near the Golconda and Columbia, important stringers leave the main ledge and continue somewhat divergent from it. These have not yet been traced out in detail. On one of these the Free Coinage claim is located, the place of principal workings being on Silver Creek, one-third mile above the Mountain Belle. Some 500 feet of work has been done and preparations have been made to sink a shaft. The vein is inclosed in black argillite, much crushed and filled with pyrite and stringers of quartz. Satisfactory ore is reported to have been found.

Ibex mine.—The group of three claims, Ibex, Nachez, and Pyrites, comprising this mine is located on the high divide separating McCully Fork of Powder River from the waters running into Granite Creek and the North Fork of John Day. The elevation at the shaft is 6,270 feet. Through openings in the forest a fine view is obtained across the heavily wooded Granite Creek Basin toward the Greenhorn Mountains. A short distance northward Bald Mountain rises to 8,330 feet. The property was bought a couple of years ago for a sum reported to be $60,000. Since then a great deal of development work has been done, consisting chiefly in a shaft 300 feet deep, with two tunnel levels, as well as a third and lowest tunnel level 800 feet long and driven 500 feet below the shaft on the Pyrites claim. Total development work, 3,000 feet. There is as yet no mill on the property.

The country rock is the usual black, hard argillite, sometimes, as at the Pyrites tunnel, showing the stratification very plainly. At this place its strike is nearly east-west and it dips steeply. A short distance northward the contact with the granodiorite of Bald Mountain begins. The vein is very strongly marked with large outcrops of mixed argillite and quartz. Its strike is E. 25° N. and its dip 60° SE. on top of the hill, increasing to 80° in the bottom of the shaft. The croppings are said to be poor, but in one spot the quartz showed free gold and a considerable amount of pyrargyrite. The vein is from 6 to 10 feet wide and shows great similarity to the North Pole–Golconda vein. In general it consists of a zone of crushed black argillite between two usually well-defined walls. The argillite is filled with irregular quartz seams, sometimes showing plain comb structure. In other places the argillite occurs as inclusions in the quartz and is partly silicified and filled with pyrite. The pay is contained in the white quartz and is chiefly in the sulphides, which consist of pyrite and arsenopyrite. The gold, when occurring, is of rather pale color and worth only $13 per ounce. Pyrargyrite and cinnabar have been found, the latter in several places as apparently secondary seams in the quartz.

The mine is reported to contain three shoots: The first, struck near the mouth of the second tunnel, 150 feet below the shaft, and called the Boulder shoot, carries no free gold nor sulphurets, but the ore cyanides well after roasting. This ore is said to carry 95 per cent of its value in gold. The next shoots nearer the shaft lie on the hanging wall and are from 3 to 5 feet wide. The second shoot contains 60 per cent gold and 40 per cent silver, and includes as a smaller, 8-foot long lens, the coarse gold chimney, known from the surface and the second tunnel level. Finally, the most easterly shoot is said to carry 60 per cent silver and 40 per cent gold. The pay in this vein is believed to be rather irregular and pockety, but is thought to possibly average $10 per ton.

Bald Mountain mine.—This is located east of the Ibex, on the same vein. It is high up on the summit of the ridge, dividing McCully Fork of Powder River from the drainage basin of the North Fork of John Day River. The elevation at the shaft is 6,300 feet.

The mine has been developed but recently, though the vein has been known and slightly prospected for many years. The intention is announced to shortly erect a 20-stamp mill on the property.

Most of the following data regarding pay shoots and development were kindly furnished by the manager, Mr. H. S. McCallum.

The Bald Mountain Mining Company owns 38 claims, of which two, the Bald Mountain and the Midnight, are on the Ibex vein, taking in 3,000 linear feet of this. The principal vein is developed by a tunnel 500 feet long and by a perpendicular shaft at the mouth of this tunnel. Two levels are turned from this shaft, at 100 and 200 feet, and sinking is in progress below the latter level.

The country rock is a hard, black siliceous argillite, often massive, more rarely showing a stratification, the strike of which is nearly due east-west, the dip being 60° S. The vein is exceedingly strong and well defined. It is a typical fissure vein, showing a width from 1 to 30 feet and averaging several feet. Its strike is N. 60° to 65° E. and its dip averages 70° S., the vein thus cuts the stratification in strike and dip.

The gangue is throughout a white massive quartz, such as normally occurs as filling in fissure veins. The vein is sometimes filled with solid quartz, though more commonly, especially in the wider portions, much of the vein matter is a shattered argillite cemented by auriferous quartz. The vein shows in its structural feature a great resemblance to the Ibex, of which it is the extension. Besides free gold and a very small percentage of pyrite the quartz occasionally contains bunches of cinnabar.

Secondary changes apparently have had little influence except for a distance of 25 to 50 feet from the surface. Several ore shoots are known. All of them carry a certain proportion of free gold and appear to pitch steeply southwest on the vein. The first shoot near the mouth of the tunnel continues for 60 feet, carrying 50 per cent of free gold and equal quantities (by weight) of gold and silver. The vein is from 8 to 10 feet wide and the tenor of the ore is stated to be from $8 to $10 per ton. A second pay shoot, 75 feet long, of lower grade is met 190 feet from the mouth of the tunnel. A third shoot, 300 feet from the mouth, is 200 feet long, the width varying from 4 to 30 feet, and the value from $6 to $50 per ton.

On the first shaft level the first pay shoot was found a short distance from the shaft, its width of 8 feet gradually decreasing to 18 inches. Thirty per cent of the gold is here free. After cutting through this shoot the drift follows the partially pinched vein for 210 feet in quartz with low values of from $1 to $3 per ton. The second and third shoots have not yet been reached. To the east this level continues in ore for 14 feet.

On the second level the first shoot was met 100 feet from the short crosscut to the vein. To the east on this level there is another ore shoot 80 feet from the shaft that has been drifted on for 60 feet. It is proposed to open the vein by means of a 1,500-foot long crosscut lower down on the slope, giving backs of 900 feet, the mill to be placed at the mouth of this adit.

A short distance north of the main deposit are two strong veins, said to carry good ore, which may be offshoots of the principal fissure. They are called Fairview No. 1 and No. 2. In a small tunnel on the latter granite forms both walls, this being probably a dike or smaller intrusive mass in the prevailing argillite.

On the same strongly marked vein as the Ibex and the Bald Mountain, and half a mile eastward from the latter, is the Grand Trunk, on which the Ibex Company had a bond in 1899. Some 1,200 feet of development work was done. The vein is said to be similar in character to those of the two mines already described.

Mammoth mine.—The Mammoth mine is located near the head of the creek of the same name, at an elevation of about 6,300 feet. The gulch, which is a tributary to McCully Fork of Powder River, widens near the mine. Thick timber covers the region, and down Mammoth Creek an excellent view is obtained over the southern part of the Blue Mountains. In the upper part of the gulch is evidence of extensive placers. The mine itself is one of the oldest in the district, having been worked by means of a primitive hand mortar, arrastre, and mill as early as 1881. A considerable amount of gold has been produced, stated by some to be as high as $150,000. The mine owned by the Bald Mountain Mining Company consists of the Mammoth and the Belle of Baker claims, both on the same vein, supposed to be an extension of the Ibex vein. In 1900 this mine was reopened, with excellent results. It is at present equipped with a 5-foot Bryan mill and four concentrators. The developments consist of an inclined shaft on the Mammoth 300 feet deep and a tunnel with drifts and crosscuts on the Belle of Baker, the latter on the west side of the creek.

One-half mile from the mine toward Sumpter the main granite contact is passed, and the prevailing rock at the Mammoth is a granodiorite. It contains, however, in places masses of argillite strongly contact metamorphosed. A contact between the two may be seen in the creek just below the mine. Most of the workings are in granodiorite, though occasionally argillite appears, as in the foot wall of the vein on the second level.

The vein, which without much doubt is continuous from the Ibex, has an east-northeast direction and a steep southeast dip, similar to the other principal veins in the vicinity. In the shaft from the upper part of which the old bonanza was extracted the vein is very wide—up to 20 and 40 feet—and consists of a crushed zone of rock, traversed by several gouge seams parallel to the ultimate walls, which are fairly well defined. The ore consists of crushed country rock cemented by quartz. Some of it is a very pretty breccia of argillite, which contains a little metasomatic pyrite and arsenopyrite, and which is cemented by crusts of calcite. The calcite again contains veinlets and druses of quartz. Neither calcite nor quartz contains any sulphides. The gold is of pale color and only 500 to 600 fine, the rest being chiefly silver. On the first level in the shaft the ore was poor, but in the second a good, though spotted, free-milling pay shoot was found containing from $6 to $12 per ton. The third level had not yet been developed.

Late in 1900 an important and rich pay shoot was found in the Belle of Baker tunnel. This was run as a crosscut for several hundred feet. The vein, when struck, proved to be 35 feet wide and to contain a 12-foot-wide ore body of crushed rock, with cementing quartz stringers and sulphurets, but no free gold. This body seemed to cut across the vein, making for the hanging wall. From this place a gouge streak in the vein was followed for 200 feet without showing any notable values. Crosscutting toward the foot wall, however, disclosed a large body of ore with much coarse gold, containing $25 to $400 per ton. At the present end of the drift a crosscut showed 16 feet of ore;

70 feet from the breast it had widened to 45 feet. A crosscut 170 feet from the breast and 50 feet from the place where the vein was first struck disclosed no ore, but an 18-foot upraise caught it 5 feet wide, so that the dip of the shoot would seem to be to the southwest. The ore consists of soft, gray granodiorite containing much calcite, and traversed by irregular seams of white vein quartz inclosing pale-colored free gold, together with a little arsenopyrite and pyrite. The gold, while to some extent directly in the quartz, seems by preference accumulated in a soft greenish roscoelite which looks much like chlorite and which is contained in spots and bunches in the quartz. Numerous smooth slips with polished surfaces of gold traverse the ore. Between the tunnel and the surface there is estimated to be between $200,000 and $300,000 in sight. This find is of interest as illustrating the necessity of crosscutting in these wide lodes. It is similar to the case of the Bonanza mine, inasmuch as a drift was long run parallel to the ore body without suspicion of its presence.

CABLE COVE DISTRICT.

GENERAL FEATURES.

The Cable Cove district is situated 10 miles in an air line north-northwest of Sumpter, on the high backbone which separates the drainage of Powder River from that of the North Fork of John Day River. The road from Sumpter follows Silver Creek, the principal fork of Powder River. For some miles above Sumpter the canyon is narrow, but soon widens and assumes the broad U-shaped form characteristic of glaciated valleys. Near Cable Cove the road emerges from the thick timber in the bottom of the valley. The head of the creek appears as a wide amphitheater with steep slopes, sparsely timbered. Westward the ridges of Bald Mountain rise with bare, light-gray, glaciated outcrops. Eastward a number of sharp and high granite peaks meet the eye in the continuation of the Elkhorn Range (Pl. LXXII). The elevation at the California mill is 7,000 feet; the high hill back of it attains 7,900. The gaps east and west of this hill are 7,500 feet in elevation. From the summit long ridges extend northward between the heavily timbered valleys of Big Limber Creek, Bull Creek, and the North Fork of John Day. The summits of Cable Cove culminate a couple of miles southwesterly in Bald Mountain (elevation 8,330 feet), so prominently visible from Sumpter. It is a bare granitic ridge, sloping abruptly northward and here inclosing a glacial amphitheater in the center of which is a small lake.

GEOLOGY.

The geological features are very simple. Cable Cove is situated in a large area of granodiorite, which begins a short distance north of the Free Coinage mine, the actual contact being covered, and which continues for many miles northward. This rock, very similar to granite, is light gray, granular, and consists of quartz, andesine, orthoclase, biotite, and hornblende. For analysis and detailed description see page 587. Glaciated outcrops seem nearly white, while on the lower slopes the sandy decomposed rock appears light yellowish. Very few dikes of any kind were noted, the exceptions being small sheets of aplite. The granitic area culminates in a series of white, high, and jagged peaks situated between the headwaters of John Day and North Powder rivers.

Beginning a short distance north of the Crown Point claim and extending for several miles northwesterly on both sides of Big Limber Creek is an area of gneiss. The rock is usually sharply defined and separated from the granite and is certainly not a dynamo-metamorphic or sheared granite; neither is it a contact-metamorphic rock. It is coarse grained, very plainly schistose, sometimes contorted, consists of biotite, quartz, and a little plagioclase, and has the appearance of an Archean gneiss. At the Grizzly claims, below La Belleview mine, the strike is N. 40° E. and the dip 45° W. This occurrence is remarkable, because no rocks similar to it have been found in any other part of the area examined.

The whole summit region from Bald Mountain to the high country at the head of North Powder River bears clear evidence of having been glaciated. The higher peaks and ridges are bare, and sometimes polished surfaces are seen, though the rapid disintegration of the rock is apt to soon destroy any such marks. Silver Creek, below Cable Cove, contains morainal material as far down as the junction of the Mammoth road below the Mountain Belle mine, the elevation here being 5,400 feet. McCully Fork, joining Silver Creek near Sumpter, was also occupied by a glacier reaching down to an elevation of 4,700 feet. How far the glacier of the North Fork of John Day descended is not certain, but it pretty surely reached the mouth of the canyon at the road crossing, where the elevation is 5,200 feet.

GOLD-QUARTZ MINES.

General statement.—The mines of Cable Cove are among the earliest discoveries in the Blue Mountains, being found in 1872 by the Cable Brothers. Some rich ore was shipped in these early years, but the great expense rendered this impracticable for the ordinary run of ore. The development of the district was slow, owing to its inaccessible location. When the overland railroad was completed, about 1885, new activity followed and many claims were worked. Shipments of ore continued at intervals, and one concentrating mill was erected. During 1900 there was more activity than at any previous time. Development work was in progress upon a great number of claims and about ten carloads of ore were shipped to smelting works. Deeper exploration will soon determine the value of the district. At present

A. CABLE COVE, LOOKING EAST.

B. LOOKING SOUTHEAST FROM CABLE COVE.

ore is hauled to Sumpter, the distance being 14 miles, and sent by rail from that point.

The deposits are normal fissure veins with northeasterly strike. One strong lode, the Eagle, is traceable for at least 2 miles, and dips steeply northwest. Most of the other veins are located on the hanging side of the Eagle and generally dip southeast, following an extensive system of parallel shearing planes. One branch of the vein system (Pl. LXIV) extends across to the head of Cracker Creek. The ores consist of heavy sulphurets, chiefly pyrite, arsenopyrite, and zinc blende, with smaller quantities of galena and chalcopyrite. Their value is chiefly in gold, and very little of it is free. Two or three miles to the northwest a nearly parallel vein system appears in the gneiss, among which La Belleview vein is the most prominent. These veins carry a considerable amount of silver besides gold. Finally, in the Monumental, beyond La Belleview vein and really outside of the district, silver is the prevailing metal. The oxidized zone with free gold is only 30 to 50 feet deep, no doubt owing to the ice sheet which once covered this region and which has swept away the decomposed vein croppings. The sulphurets below the water level contain a little free gold.

Eagle vein.—The Eagle, which is considered as the mother lode of the district, continuing in strong development for 2 or 3 miles, is the first vein met with going up on the road from Sumpter. The developments and production of the Eagle are as yet comparatively very small, but great hopes are placed in it for the future. It is traceable with a north-northeast strike through the Homestake and Oregon Chief. The Oregon Chief has 800 feet of developments and an ore shoot claimed to be 8 feet wide and containing $12 per ton.

The vein on the Herculean claim is well exposed by a surface cut at Silver Creek, showing a width of 15 feet between granitic walls. The vein material is an altered granodiorite, traversed by at least two streaks of arsenical pyrite half a foot wide. The vein now turns more nearly northeast, and on the adjoining claim, the Black Dwarf, preparations were made in 1900 to sink a 300-foot shaft.

On the northwest side of Silver Creek the Herculean is covered by the Eagle claim, on which a 400-foot tunnel has been driven. In a width of 15 feet of altered granite the vein here contains overlapping pay streaks from 2 to 3 feet wide, reported to average something like $12 per ton.

Imperial mine.—The Eagle Consolidated Mining Company owns nine claims in the district, among them the Eagle, Imperial, and Winchester. The latter two have been actively worked during the last two or three years. In 1900 160 tons of ore, with a value of $120 per ton, is reported to have been shipped. The developments consist of 1,500 feet of tunnels. The present working tunnel is located one-fourth mile northeast of the old California mill, at an elevation of about 7,200 feet, 250 feet below the gap. Several hundred feet of additional backs can be obtained by a lower tunnel about 1,500 feet long.

The claims are located on veins in the hanging of the Eagle lode, which is about 800 feet distant. Northwestward from the Eagle a small vein called the Star is the first met with; then follows the Imperial, and a short distance farther the Winchester. Granodiorite is the country rock in which the inconspicuous croppings appear. The strike is N. 35° E; the dip of the Imperial 70° SE., while the Winchester is nearly vertical. The veins are from 3 to 4 feet wide, the vein matter consisting largely of granodiorite slightly crushed and darkened by the spreading of chloritic material. The pay streak is usually on the hanging wall and consists of from a few inches to a foot of nearly massive sulphurets with a small quantity of quartz and calcite gangue. Surrounding the pay streak is a belt a few inches wide of white, soft granodiorite, thoroughly sericitized and carbonatized. Seams striking in a northerly direction and dipping 70° W. come in on the Winchester from the hanging wall, but do not cut back into the foot wall. They carry circulating water and sometimes contain a little quartz and altered granodiorite. Both vein walls and seams show a horizontal striation.

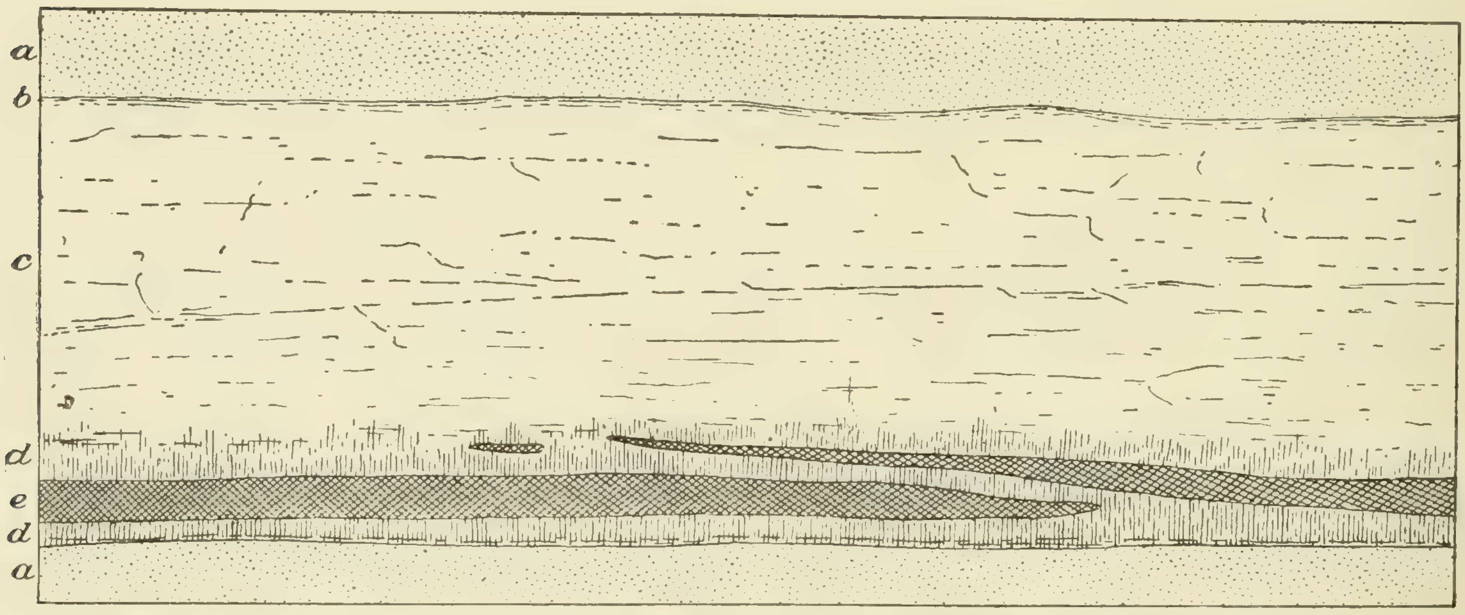


FIG. 82.—Structure of vein in Cable Cove district; width, 4 feet; horizontal projection; *a*, fresh granodiorite; *b*, hanging wall with clay gouge; *c*, crushed granodiorite; *d*, altered (sericitized) granodiorite; *e*, sulphurets with little quartz and calcite.

The ore, most of which is high grade, occurs in irregular and overlapping lenses (fig. 82). The seams mentioned generally cut off the ore, the latter usually reappearing a few feet farther on. Material with over $25 per ton is shipping ore. The 160 tons shipped in 1900 are stated by Mr. F. C. Cabell to have contained as high as 6 ounces of gold and 80 ounces of silver per ton. While the principal values are thus found in narrow streaks of rich ore, there are also in places, especially in the Imperial, smaller shoots, a few feet wide, of second-class concentrating ore. The stopes above the tunnel level are 150 feet high.

The ore minerals are galena, arsenopyrite, chalcopyrite, and pyrite, with a little zinc blende. The galena appears to be the earliest mineral and is often cemented by the others. Massive structure prevails. These sulphurets contain a little free gold, apparently chiefly connected with the galena and the zinc blende. About 10 per cent of the total gold can be recovered by amalgamation. Some nearly pure galena was assayed and contained 0.74 ounce gold and 60.86 ounces silver per ton. The arsenopyrite contained 5.82 ounces gold and 7.08 ounces silver per ton.

California mine.—The California claim is 1,200 feet to the northwest of the Eagle vein, and is one of the oldest mines in eastern Oregon. It was located in 1873, and in 1876 the upper tunnels were begun. At that time there were only two other quartz mines in operation, the Monumental and the Virtue. In 1878 half a ton of ore, assaying $500 per ton, was packed on horseback to Umatilla and thence shipped to San Francisco. In 1896 a shipment of 5½ tons is reported to have yielded $105 per ton. Further shipments were made in 1893 and 1894 of ore assaying $60 to $80 per ton, and in 1897 several carloads were produced.

In 1897 a 10-stamp concentrating mill was built and run with unsatisfactory results for a short time. It is claimed that the whole width of the vein was milled, thus reducing the grade of the ore too much. During 1900 five cars, or 100 tons, are reported to have been shipped. The total production is not known, but probably does not exceed $40,000. The developments consist of 2,000 feet of drifts and crosscuts divided among six tunnels. The lowest working tunnel from which ore was extracted in 1900 is located on the steep slope 400 feet below the croppings. Its elevation is about 7,200 feet, its length 635 feet. A new crosscut, to be 900 feet long, is now in progress 400 feet lower down, 1,300 feet below the summit of California Mountain and 800 feet below the croppings.

Similar to the other veins northwest of the Eagle, the California shows inconspicuous croppings in granodiorite, strikes northeasterly, and dips steeply southeasterly. There is also on the property another parallel vein on which little work has been done. The ore is similar to that of the Imperial, consisting of heavy sulphurets in a gangue of little quartz and still less calcite. The ore seems principally of the shipping order, forming narrow streaks in a 3-foot-wide vein.

Other claims.—Above the mines just described California Hill is traversed by a great number of shearing planes, along nearly all of which more or less ore has accumulated. The developments are generally confined to short tunnels and small shafts. The extension of the Imperial is probably found in the Last Chance on the John Day side of the hill. From a tunnel on that claim some arsenical ore has been shipped. The probable continuation of the California is found in the Ivy May. In the gap toward Bald Mountain is the Crown Point (elevation of croppings, 7,500 feet), which shows on the surface as a rusty belt of granitic rock traversed by seams of quartz and pyrite. An 800-foot crosscut tunnel is now being driven on this claim.

On the ridges between Bull Creek and John Day River, 1½ miles north of the California, is a group of veins with an east-northeast strike to which much attention has been directed lately. Among them is the Baby McKee vein, which is now being tapped by a 2,000-foot-long crosscut tunnel.

Other groups of veins extend with a northeast or east-northeast direction to a point 3 miles east-northeast of the California. Near the head of Cracker Creek, 2½ miles above the North Pole vein, this vein system crosses the contact of granodiorite and argillite. At least two veins enter the dark-gray, somewhat contact-metamorphic argillite. The Silver King, at an elevation of 7,000 feet, is developed by a tunnel 200 feet long and shows comb quartz with cubical pyrite; the width of the vein is 5 feet. Another vein, south of the Silver King, the Emma, is opened by a tunnel on creek level at an elevation of 6,400 feet; it strikes about east to west and dips 60° S. The width is 2 to 3 feet between walls, with a 6-inch pay streak of quartz, calcite, pyrite, and arsenopyrite. The principal value is in gold. This locality is called Quartz Basin, and some years ago a 5-stamp mill was erected here. The ore proved only partly amenable to amalgamation.

Out on the long ridges between Bull and Lake creeks are other veins which have been prospected recently. Having the same easterly to northeasterly strike, these veins are inclosed in a normal biotite-gneiss, which begins near the Rob Roy claim and continues several miles beyond La Belleview mine.

CAMP CARSON DISTRICT.

The mountainous and heavily timbered country north of Cable Cove does not contain extensive mineral deposits. Camp Carson, 20 miles in an air line north of Sumpter, is the principal mining district known in this region. Lying at the western foot of the high granite peaks of the Elkhorn Range near the head of the Grande Ronde River, it is accessible only by wagon road via Granite and Woodley, or by going up the Grande Ronde Valley from the town of Hilgard. This district was not visited; the following notes were obtained from Mr. Imhaus, of Baker City:

The formation is reported as granite. Near Hunters, 3½ miles below Camp Carson, on the Grande Ronde, are prospects on gold-quartz veins containing much sulphurets. Among them are mentioned the Royal, 6 miles south of Woodley. The vein is said to be

7 feet wide and to contain chalcopyrite and galena rich in gold. From the Pay Boy, 1½ miles southwest of Woodley, two carloads of ore are said to have been shipped. From the Muir zinc blende and galena, with good silver value, are reported.

Old placers have been worked in the Grande Ronde below Camp Carson, and also on Limber Jim Creek, 6 miles northward. Camp Carson itself is located at the head of Tanners Gulch, 1,200 feet above Grande Ronde River. These high placers contain a large body of well-washed, cemented, coarse gravels, presenting a bank 2,500 feet long and generally 15 to 20 feet high. This body of gravels is not exactly situated on the divide, as there are granite hills rising behind them; but it is apparent that they must have been deposited by a river system at very different level from that of to-day, and it is probable that they should be placed in the same category as those of the Griffith claims below Bald Mountain (p. 688). While the gravels contain gold, their cemented nature interferes with the normal hydraulic process. A French company bought the deposits some years ago and installed hydraulic works, but the enterprise did not succeed well and the property was recently sold at auction.

GRANITE DISTRICT.

GENERAL FEATURES.

Under the Granite mining district will be described the headwaters of the North Fork of John Day River, Granite Creek, and its various tributaries above the town of Granite. The North Fork heads among the granite peaks of the northern Elkhorn Range, near Cable Cove, and flows in a general westerly direction for 20 miles. At this distance from its source it receives the tributary of Granite Creek, the different branches of which head in the gulches scoring the flanks of Bald Mountain and the ridge extending southeasterly from it toward Sumpter. From Bald Mountain northward the headwaters are among high and bare peaks, once glaciated, with elevations of about 8,000 to 8,500 feet. But the whole western part of the drainage area is a maze of deep gulches and moderately sharply cut canyons, separated by long timbered ridges which rarely attain elevations over 6,000 feet. The elevation at Granite is 4,680 feet. The region embraces old placer mining districts worked since 1863, and, as well, some of the most promising quartz mines developed in the last few years. The old mining town of Granite, which has recently acquired new life, is in the center of the area. A new town, called Lawton, has recently been started 2 miles below Granite. The region is splendidly watered and heavily forested, though there is but little yellow pine. The quality of the timber is not nearly so good as in Burnt River Valley and on the Middle Fork of John Day.

GEOLOGY.

Among the older rocks the argillites of the sedimentary series are the most extensively developed formation. They form a large area extending from the granodiorite of Bald Mountain westward until, below Granite, they are covered by basaltic flows. South of the Sumpter–Granite road they are especially prominent. The dark siliceous argillites prevail, but fairly fissile, black, and normal clay slates are not absent. No limestone was noted, neither have any fossils of any kind been found, so that the age of this formation is an open question. It is, however, clearly the continuation of the series developed at Sumpter and, like those series, may provisionally be regarded as Carboniferous. The strike and dip of the strata are not always easy to determine, on account of the massive character of the siliceous argillites; on the whole the strike is a few degrees north of west and the prevailing dip is southerly at steep angles. But in the vicinity of intrusive granodiorite or diorite this strike is frequently deflected. Thus the strike follows the contact of the Bald Mountain granitic area with northwesterly direction and dips of from 60° to 80°, and again near Alamo a northwesterly direction and northeasterly dip of 60° to 70° obtain. At Red Boy mine the clay slates appear in a very exceptional flat position dipping 15° W. These deviations are doubtless explained by the presence of intrusive diorites just west of these localities. Near the Bald Mountain contact the slates are contact metamorphic and schistose, while the alteration near the diorite of Greenhorn Mountain is less conspicuous.

The intrusive rocks include granodiorite and diorite. The granodiorite area of the northern Elkhorn Range and Bald Mountain projects southward from the latter peak along the ridge separating the drainage of Powder River from that of John Day, and it extends a little south of the point where the Granite–Sumpter road crosses that ridge. The rock is here coarse grained and dark; in fact, approaches closely to a normal diorite. Diorites of more basic character and closely connected with gabbro and serpentine appear west and southwest of Red Boy mine. Again, 8 miles north of Granite, on the north side of John Day River, a medium-grained, dark diorite appears rather extensively. The canyon below Klopp's placers is cut in this diorite, which often is irregularly crushed and recemented like the rocks described from the Virtue mining district and the southern end of the Elkhorn Range.

On Onion Creek and Lake Creek, north of Bald Mountain, an area of normal gneiss appears, which has already been described under the heading "Cable Cove" (p. 672).

The Neocene volcanic rocks are represented by andesite and basalts, which, however, do not cover as large areas as farther south; but there is reason to believe that the basalts occupy vast areas north and northwest of Granite, down the North Fork, and on the Grande Ronde. Rhyolites are apparently not represented. A gray, in part tuffaceous hornblende-andesite fills the bottom of Bull Run from 5 miles above Granite to a point on Granite Creek a short distance below the town. The thickness of the flow is from 50 to 100 feet. The same rock also appears on Granite Creek, 4 miles above the town. Post-andesitic erosion has almost cut through the flow, so that narrow bluffs remain on both sides of the creek. The rock is compact and easily dressed, and can be used with advantage as foundations for machinery and boilers. Whether the andesite is older or younger than the basalt is not definitely settled. It certainly has the appearance of being covered by basalt, and this would correspond to the sequence established in the Burnt River drainage.

Normal olivine-basalts cover small areas near the Powder River divide where crossed by the Sumpter-Granite road. A small patch was also found at the Griffith placer mine, north of that road. Again, on the road leading by the Magnolia mine to Klopp's placers, on the North Fork, basalt begins near the divide at an elevation of 5,600 feet and continues northward over Crane's flat toward Klopp's placers and eastward as far as the Grizzly mine, on Onion Creek, below La Belleview. Over this area the flow, which appears to be rather thin, is largely covered by clays and gravels.

The largest basaltic area is that which begins just below Granite and extends high up on the hills north and south of the creek. Bluffs of basalt line the creek at least down to 4 miles below Granite, and their elevation is not less than 5,000 feet, or 700 feet above the stream bed. On the south side these basalt flows connect with the large areas surrounding the headwaters of Desolation Creek and Olive Lake. The points of eruption of this basalt must have been located on the higher slopes of the Greenhorn Mountains.

It is clear that these basaltic flows dammed Granite Creek, and probably also the North Fork, to an elevation of at least 5,000 and possibly 5,500 feet, creating even more favorable conditions for the accumulation of sediments than in the upper Powder River and Burnt River valleys.

This damming explains many peculiarities in the upper drainage of Granite Creek. Soft sediments, similar to lake beds, are found in many places, and, resting on them, auriferous gravels which could not possibly have attained such positions except through a considerable elevation of the base-level (see description of Griffith's placers, below). The erosion has proved more active on this side than on the southern side of the mountains, which, indeed, was to be expected, as erosion has cut down much lower on the northern side. The barrier has been almost entirely cut through and the greater part of the sediments swept away. If we place the accumulation of the beds behind the barriers in the late Neocene (Pliocene), it is probably correct to refer the cutting of the canyon in the basalt to the early pre-Glacial part of the Pleistocene period.

The Pleistocene deposits are confined to the present river beds and the low benches, as well as to the moraines. The bottoms of Granite Creek and Bull Run as far as 4 or 5 miles above Granite are filled with gravels, forming a continuous flat up to a few hundred feet in width. For several miles below Granite the creek bottom continues several hundred feet wide and filled with tailings. Gravel benches sometimes occur along the banks from 25 to 50 feet above the creek.

Moraines are not extensive in this district. The gulches leading down from the north slopes of Bald Mountain were filled with glaciers, and it is probable that the moraine extended down to Klopp's placers (elevation, 5,200 feet).

Another center of former glaciation is in the Greenhorn Mountains. On their northern slope smaller glaciers descended as far as Olive Lake.

GOLD-QUARTZ VEINS.

General statement.—The important veins in the Granite district are chiefly contained in the argillites, and present in general a similarity to those of Sumpter and Cracker Creek districts. There are two prominent vein systems: The first extends from the Cougar mine in a northeasterly direction toward the Magnolia and Buffalo, and the veins dip southeast at steep angles. The second is developed near the Red Boy mine, the veins having a northerly strike and dipping west at angles of from 50° to 70°.

Red Boy mine.—This well-known property is situated on Clear Creek 15 miles in an air line west-northwest of Sumpter and 4 miles from Granite. The elevation of Clear Creek at the mill is 4,610 feet (by level), and the tunnel level is only about 60 feet higher. Heavily forested ridges surround the mine. The Red Boy for many years was worked intermittently and with indifferent results. Two mills were erected on it, each failing to achieve success. After that, Messrs. Taber and Godfrey, the present owners, built a small Crawford mill, which did excellent work for some time. Finally, in October, 1898, the present 20-stamp mill was installed, which has run uninterruptedly and successfully until the present time. As is so often the case, data regarding the total production were not obtainable, but as the mill is currently credited with turning out from $12,000 to $27,000 per month, it may be presumed that the total production since 1898 has not exceeded $300,000. The property is equipped with a 20-stamp water-power mill with amalgamating plates and 8 vanners. The low-grade concentrates are treated without roasting in a small cyanide plant, the percolation extending over thirty days. This would indicate that value is in free gold adhering to the sulphurets.

The developments on the adit level consist of a main crosscut 1,200 feet long, 470 feet below the summit of the croppings, and drifts aggregating 3,000 feet. At present sinking is in progress on a vertical shaft located on the surface a short distance above the tunnel (Pl. LXXI, *B*).

The country rock is a black argillite, not very fissile, but showing its stratification fairly plainly. The strata are here unusually flat, dipping about 15° W. The argillite, which changes in character from siliceous to calcareous, is in many places cut by light-gray, extremely altered porphyritic dikes, which have the appearance of cutting across the vein and faulting it. It is believed, however, that the veins are really later than the dikes; that the fissures in crossing them were, as often happens, split up in stringers; and that a subsequent movement has occurred along the walls of many of the dikes, so that the veins now appear dislocated by them. The dikes are so greatly altered that their original character is in doubt. Probably they were originally granite-porphyries, but now consist chiefly of quartz, calcite, and pyrite. Several of them are seen in the crosscut to the vein, one being 60 feet wide.

There are three veins, the Blaine, Red Boy, and Monarch, all of them having an approximate northerly strike and a varying westerly dip. The Red Boy dips 80°, the Monarch 50° to 60°. The outcrops are not very prominent, and the pay shoots not conspicuous on the surface. The general structural relations are diagrammatically shown on fig. 83. The Blaine is located 300 feet west of the Red Boy, and has not yet been struck in the crosscut. It appears on the surface as a wide vein with fair values. In their general character the veins are similar to those of Cracker Creek, though they are not so wide. They consist of a crushed fault zone in argillite, from 3 to 15 feet wide, in which the broken rock is cemented by a great number of quartz seams. The two veins converge slightly and nearly meet at a main porphyry dike dipping 60° S., along which they have been sharply cut off by a smooth fault. The veins have not yet been found beyond the dike, though from surface indications it is probable that the northern block has moved, relatively, 400 feet to the east. A similar dike, 10 feet wide, faults the Monarch vein 10 feet through all levels, the throw being in the same direction as that along the big fault. Another dike cuts across the Red Boy horizontally, and still another has produced a sharp twist of the vein in the same direction.

The structure of the vein is well shown on Pl. LXV, *B*, which is drawn from a photograph of a stope on the Monarch vein a short distance above the tunnel level and near the northern end of the shoot. The foot wall of the Monarch is usually smooth and sharply defined, while the hanging is less well marked, a definite wall being often entirely absent. The width between walls varies from 5 to 7 feet. The vein matter is a black, crushed slate, and sometimes, also, masses or bunches of soft porphyry, both containing finely divided pyrite. This vein matter is traversed by a number of small quartz seams, rarely over 4 inches wide. Most of the seams are on the foot-wall side and produce a banded appearance of the vein. The best pay is contained in the 2 feet on the foot wall, though the whole width is mined. In a few places on the Monarch vein bunches of 5 to 6 feet of solid quartz were found. The seams usually show clearly defined comb structure, the crystals projecting from both sides of the seams meeting in a median line. There is no evidence of surface oxidation of the Monarch on this level.

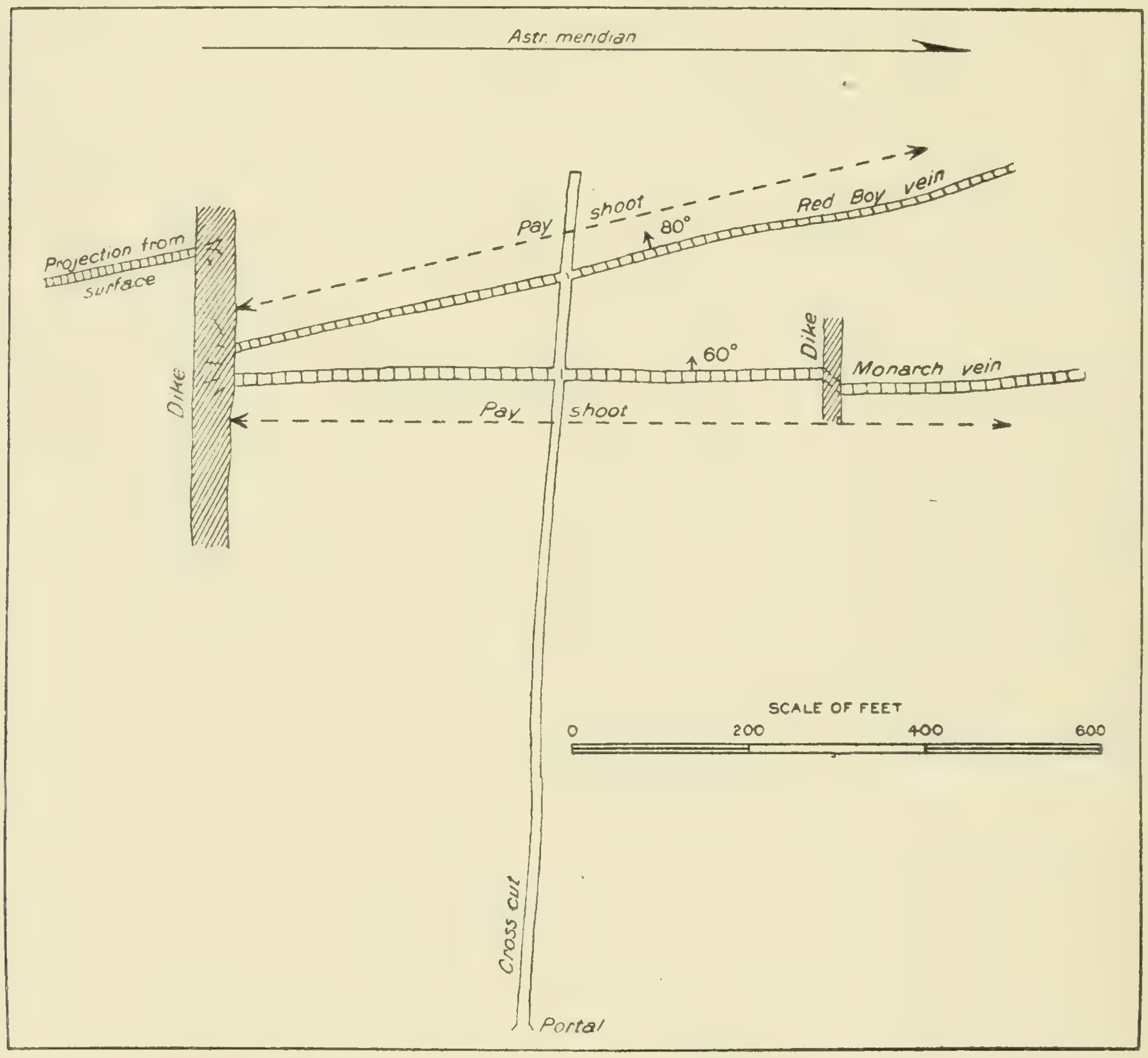


FIG. 83.—Approximate plan of Red Boy mine on tunnel level.

The Red Boy vein averages from 3 to 6 feet in width and is in general structure similar to the Monarch (fig. 84), though the quartz is apt to form somewhat heavier bodies. It also contains more clay than the Monarch vein.

The value of the ore appears to be entirely contained in the quartz seams and consists chiefly in free gold alloyed with much silver, the bullion being from 515 to 525 fine. The quartz contains a small amount of sulphides, pyrite with very little chalcopyrite, and arsenopyrite. In some parts of the mine cinnabar and native mercury have also been found. This is given on authority of Mr. J. Arthur, an assayer at Sumpter, who also states that at one time, when the Crawford mine was running, more mercury was obtained from the amalgam than had been added. Metallic silver and copper have also been found on the Monarch vein, inclosed in white massive quartz, and thus probably primary. The 5 per cent sulphurets contained in the ore are low grade, from $5 to $20 per ton, and probably are largely contained in the slate milled with the quartz. The average ore is reported to run about $12 per ton.

The ore shoots on the two veins almost coincide in extent, and it is said that even the richest places in them correspond. On the surface, however, the pay shoot of the Red Boy was only 100 feet long, and that of the Monarch did not reach the surface at all. The horizontal extent on the tunnel level is 800 feet. North of this the Monarch vein consists of crushed slate with small stringers of quartz. Considerable ore bodies still remain above tunnel level.

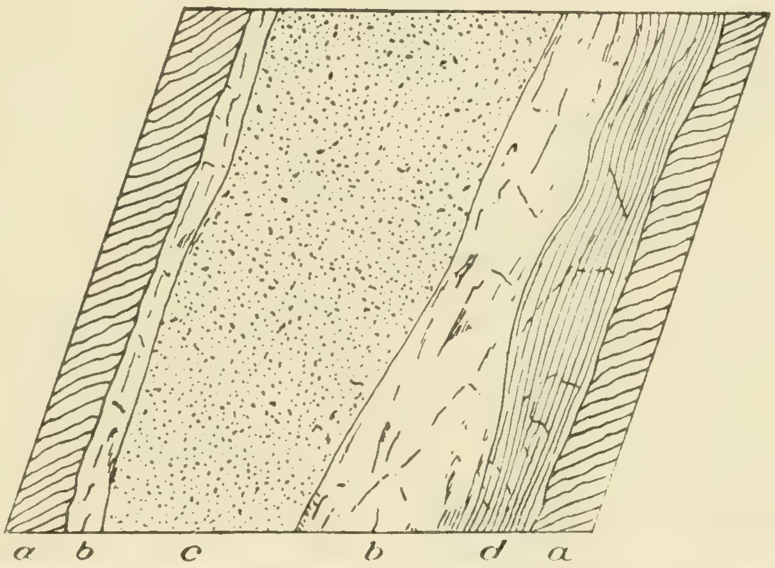


FIG. 84.—Vertical section of Red Boy vein in stope 100 feet above tunnel level; *a*, slate; *b*, quartz; *c*, soft altered porphyry; *d*, clay.

Claims near the Red Boy mine.—Among the many more or less developed claims near the Red Boy is the May Queen, which is about one-fourth of a mile distant, and, with four claims, covers the northerly extension of the Red Boy veins. The developments on the May Queen and adjacent claim consist of about 1,600 feet of tunnels and crosscuts, opening the vein to a depth of 350 feet below the croppings. In general character the ore issimilar to that of the Red Boy. A mill was erected during the winter of 1899–1900, but was run only a short time.

The Concord group of four claims adjoins the Red Boy on the west, and a considerable amount of prospecting work has been done here also.

Cougar mine.—About 4 miles north of Granite and only a short distance from the Magnolia is the Cougar vein. The elevation is 5,300 feet, and, like the Magnolia, it is not far from the main divide between Granite Creek and North Fork of John Day. Its discovery is of comparatively recent date. During 1900 it was actively worked, and a small cyanide plant had just been erected. The treatment of the ore seems to offer some difficulties, like that of the Magnolia.

The developments extend over a vertical distance of 200 feet and consist of several smaller tunnels and shafts. The lowest tunnel, on mill level, strikes the vein after a short crosscut and follows it for 900 feet. The country rock is a black, siliceous argillite of imperfect fissility. Its strike near the tunnel is N. 80° E., and the schistosity nearly vertical. The outcrops are not conspicuous, and show plainly only on top of the ridge. The strike is due northeasterly and the dip 60° to 70° SE. The Cougar vein forms a sheared zone in the argillite from 2 to 10 feet in width, and is marked by two not very well-defined walls and several subordinate slips. There is a little quartz with some pyrite, but this is said to generally carry low values. The ore streak is formed by the soft, whitish gouge of varying width which follows the vein. Some of this is stated to be very rich, and the whole length of the main tunnel is claimed to be in ore. The values gradually shade off toward the outside, so that it would seem that, in contrast to many other slate veins, this is a typical replacement vein. The gouge, and also to some extent the slate adjoining the vein, carries finely divided pyrite and marcasite, and probably also a very small amount of arsenopyrite. There is no free gold even in the surface ore, and the concentrates are poor, running from $5 to $7; consequently, considering the value of the ore, it was believed that the cyanide process might be applicable. A sample of the soft gouge said to constitute the best ore yielded 0.68 ounce gold and 23.88 ounces silver per ton. Half a mile to the southwest is the South Cougar, supposed to be located on the extension of the Cougar vein.

Magnolia mine.—This is located about 5 miles north-northwest from Granite. The road leads up Granite Creek for 4 miles and then up a narrow gulch for 1½ miles. The elevation at the mill is 5,300 feet. Ascending some hundred feet farther brings one to the summit of the divide between the North Fork of John Day and Granite Creek.

The Magnolia mine was bonded in 1899 by English capitalists and a 10-stamp mill erected. Work was discontinued after a short run, and in the summer of 1900, when visited, the mine was idle and a large pile of concentrates heaped up outside the mill.

The developments consist in three tunnels, the lowest, at mill level, being 760 feet long, giving a depth on the vein of 286 feet. The two upper tunnels aggregate 550 feet in length.

The country rock is black argillite or clay slate. At Granite Creek below the mine the slates are distinctly contact metamorphosed, indicating the proximity of the granite contact. The slates near the mine show distinct fissility, strike N. 35° W. and dip 60° SW.

The vein strikes northeasterly and is said to show from 3½ to 14 feet of mixed quartz and slate. In tunnel No. 1 two pay shoots are reported, 190 and 140 feet long; and in the middle tunnel is another pay shoot, 400 feet long. In all about 30,000 tons of low-grade ore are said to be in sight. The richest ore is found in the upper tunnel.

It is stated that during the short run 2,000 tons of ore, with a value of $9 per ton, were treated. Only a small percentage of the assay value was saved. The ore contains a considerable amount of pyrite. The concentrates were found to assay 0.94 ounce in gold and 1.38 ounces in silver per ton.

Blue Ribbon and Buffalo mines.—These are located in slate on the main ridge a couple of miles northeast of the Magnolia, and may be considered as in the extension of the Cougar-Magnolia vein system. The claims are developed by tunnels aggregating 800 feet on each and said to show good ore bodies. The Buffalo is opened by a crosscut 300 feet below the croppings, and 300 feet of drifting along the vein has been done.

Monumental mine.—This is one of the oldest locations in the district, being discovered in 1874 by Mr. Burnham. Fourteen tons of ore, shipped the same year to San Francisco by pack train, netted $500, the ore containing much silver and no gold. Some ten years later the mine was sold to an English company, who erected a silver mill to treat the ore. At present it is idle, the last work having been done in 1894. The surface vein crops in granitic rock and has a northeasterly strike. It was 18 inches wide and showed a 4-inch pay streak extremely rich in ruby silver and argentite.

The development consists chiefly in a tunnel 1,400 feet long, 600 feet below the croppings. This tunnel is said to cut 16 veins, generally small and contained in hard rock. The southeasterly vein dips very steeply northwest, the others dipping 35° against it, so that they would eventually join. Higher gold values are found in depth than on the surface.

La Belleview mine.—This is also one of the oldest locations, being claimed in 1877 by Mr. F. E. Cabell, to whose kindness the following notes are due. In early days considerable ore was shipped by pack train to Umatilla, and thence by water to San Francisco. A Huntington mill of a capacity of 35 tons per day with concentrators was erected in 1897 and run until 1899. The veins, on which about 7,000 feet of development work has been done, crop in a normal biotite-gneiss, and are located on a main ridge projecting from Bald Mountain toward Granite. The elevation is 6,500 feet; the summit of the ridge above the mine is 7,303 feet. There are two parallel veins with a northeast strike and with a steep northwest dip on the surface, changing to a similar southeast dip in depth. The gangue is quartz with a little calcite. The ore minerals are pyrite, chalcopyrite, galena, pyrrhotite, and strongly argentiferous zinc blende. Among rarer minerals occurring are native wire silver, argentite, tetrahedrite, stephanite and freibergite, the latter containing 1,000 ounces silver per ton.

The ores contain up to 7 per cent lead and $\frac{1}{2}$ per cent copper; shipping ores run from $60 to $600 per ton, one-third of the value being gold, lately increasing with depth to one-half. The concentrates contain $60 per ton.

In the canyon leading down from La Belleview mine to the North Fork of John Day are several veins cropping in gneiss. One of these, the Grizzly, is located 2 miles below La Belleview mine and has a north-northeast strike. It is developed by three tunnels and shows on the surface with wide rusty croppings. The gangue is quartz accompanied by much low-grade pyrite in heavy masses.

PLACER MINES.

The placers of Granite have been worked since 1862, but were scarcely as rich as those of other celebrated districts. A large part of the mining has been done by Chinese. In 1870 there were 40 white men and 200 Chinese in this district (Raymond's report, 1870). The production is not mentioned. In 1882 the Granite placers produced $20,000, in 1889 $20,000, in 1891 $8,500, in 1892 $28,800 (Mint reports). The present placer production is apparently fairly steady, a number of small mines having been worked for many years with constant output. The total output does not exceed $20,000 per annum.

The gravels in the stream beds of Granite Creek, Bull Run, and Clear Creek have been worked, chiefly by Chinese, for several miles above Granite; and below that place Granite Creek has also been worked. The gravels averaged 9 feet deep and from 50 to 300 feet across. Low gravel bars 30 feet above the river were also washed. Work on these gravels ceased about ten years ago.

The North Fork of John Day has been worked from a point 7 miles northwest of Granite, where Thornburg's placers are located, up to Klopp's placers, where the Grande Ronde road crosses the stream. But little gold was found above Klopp's. Thornburg's placers, which were not visited, have been worked steadily for many years, and with an annual output of several thousand dollars.

The Black Pine placers are situated on a small flat at an elevation of 4,800 feet, a mile below the Cougar mine. They have been worked recently on a small scale. The gravels, of coarse argillite cobbles, rest on a bed rock of volcanic breccia. Johnson placers, on Crane Flat, have been worked successfully for many years. A system of ditches and reservoirs supplies water for a long season. Two hydraulic giants are operated. The gravels are said to be unusually rich. The mines are situated a short distance north of the divide separating Granite Creek from the North Fork and at an elevation of 5,500 feet, 5 miles north of Granite. Going up the steep gulch in which the Magnolia mine is situated, one crosses a small basalt flow at the divide. From here down to the North Fork extends strongly contrasting, gently sloping ground with clayey and gravelly soil, covered with poor forest and a succession of flats and meadows. The clays are covered by thin gravels, which are washed and which probably derive their gold from the Buffalo and Blue Ribbon veins, situated a short distance above on the main ridge.

Klopp's placers are situated on the North Fork, 2 miles north of Crane Flat, the river here having an elevation of 5,200 feet. These diggings have been worked for many years on a moderate scale and are said to have regularly produced from $3,000 to $6,000 per year. The deposit is certainly one of the most remarkable that has come under observation.

The clays and sands of Crane Flat continue down to the river and the workings extend in irregular pits up to 130 feet above the stream. There is, as a rule, no bed rock visible, though the sediments lean against a high western rim of diorite in which the river has eroded a narrow canyon; but in one place a projecting point of argillite laid bare by the hydraulic work appears in the diggings, and at another place a small knob of basalt occurred below the gravel. The pay dirt is a most peculiar mixture of sand, fine, well-washed gravel, and heavy, partly rounded bowlders of granodiorite and diorite, and also of basalt and slate. The bowlders are irregularly mixed in the clayey sand and the gravel, which rarely shows any stratification. In one place, however, strongly pronounced fluviatile bedding was noted in a bank of sand underlying 12 feet of heavy bowlders mixed with sand. The gold is well washed and generally fine. The gravels are not rich, but the gold seems equally distributed through the mass.

The explanation of this deposit is probably to be found in the damming of the river by Neocene basalt flows to a level of 5,500 feet, and a simultaneous accumulation of gravels in the basin thus produced. There does not seem to be any deep channel through which the North Fork could have found an outlet toward Granite Creek, but the clays and gravels probably do cover the auriferous channel of an old tributary to the North Fork coming down from the vicinity of La Belleview and Buffalo mines. To judge from the granitic bowlders so abundantly scattered over this deposit it seems probable that the moraine of the glacier which once filled the upper valley of the North Fork reached down to this elevation and that the Neocene deposit has been worked over by glacial agencies.

Throughout the upper drainage basin of Bull Run above Granite many observations show that, in this watershed also, a damming by basalt flows similar to that below Granite has taken place and that the whole basin once was a lake which received fine sediments and along the margin of which, during its highest stand and during its gradual recession by canyon-cutting, the streams deposited their auriferous gravels. The best evidence of this is found at the Griffith placer mine, located 6 miles northwest of Sumpter. The road from Sumpter to Granite passes over a low gap (elevation 5,800 feet) in the ridge separating Powder River from the Granite Creek drainage basin. Descending the slope toward Granite, one finds that the diorite of the dividing ridge soon disappears, and at an elevation of 5,300 feet the gentle slopes and small flats are covered with a clayey material with scattered, well-washed gravel. Nearly all the gulches in this vicinity have been worked with more or less success. Two miles below the summit a roads leads off to the north, crosses Beagle Creek, and ascends Canal Creek some distance. The latter contains a considerable amount of auriferous gravel still available for placer work.

Griffiths Camp is situated a short distance above Canal Creek, at an elevation of 5,289 feet, or 860 feet above Sumpter. To the west rises the main dividing ridge of granodiorite, about 700 feet above the placers. About the mines there is gently sloping ground, a sort of an ill-defined bench, below which the ground falls rapidly toward Bull Run. The gravel forms a small body on the north slope above Canal Gulch and extends, apparently resting on the slope of the hill, for 1¼ miles in a northwesterly direction. Back of it is high bed rock, but in front the downward slope of the country is unbroken. A hydraulic pit about 1 acre in extent has been made in the high gravels, and a bank 40 feet high is exposed. The gravel is fairly fine, sandy, extremely well washed, and shows fluviatile stratification. On the bed rock lie coarser cobbles of slate and porphyry, also well washed. The continuation of this body in a northwesterly direction is not well exposed, but it seems to lie on a slope, and the extent and depth are difficult to estimate. Although a part of the gravel doubtless rests on diorite, the portion exposed in the pit lies on well-stratified beds of clay, with coaly layers dipping 30° toward the main divide. Thirty feet of these clayey beds are exposed, resting on granitic bed rock. The gold in the gravels is fairly coarse, but it is not probable that the material is very rich, though it may well pay for washing. On the slopes below the deposit and in Canal Gulch the gold has been reconcentrated, and these gravels are much richer. A small area of basalt covers a hill rising 150 feet above the gravels and seems to directly overlie the latter.

The water supply is taken from Canal and Boundary creeks, on the western slope of Bald Mountain, the ditches aggregating 9 miles in length.

ALAMO DISTRICT.

GENERAL STATEMENT.

From the Red Boy to Alamo, a distance of about 4 miles, the argillite continues, no igneous rocks being seen. Near the town of Alamo Clear Creek receives two branches, Olive and Beaver creeks. On all three creeks above Alamo good prospects occur and all of the veins crop in argillite. On Beaver Creek several promising properties are said to be located, but this part of the district was not visited. The claims described below are situated on Clear Creek and Olive Creek. The creeks have been extensively worked for placer gold, Olive Creek and its upper tributary, Quartz Gulch, being especially rich. A belt of diorite, serpentine, and gabbro begins a short distance west of the Red Boy and continues south, crossing Clear Creek some miles above Alamo. Higher up on its tributary, Spring Creek, at the Little Giant mine, the argillite again appears. The slates near the head of Olive Creek contain strata with detritus of igneous rocks, chiefly surface lavas erupted simultaneously with the deposition. The slates are of the usual character, black clayey argillites, alternating with dark siliceous and cherty rocks. At Alamo the strike is north to northwest, the dip east at angles of 60° to 70°.

QUARTZ VEINS.

Alamo claim.—This is located on the ridge between Olive and Clear creeks, three-fourths of a mile west of Alamo, 650 feet above the latter and at an elevation of about 5,550 feet. It was located in 1899 and as yet is not greatly developed. The country rock is a soft, decomposed argillite, in part siliceous. The vein strikes N. 25° E. and dips 60° ESE. The general character is that of the usual type of composite veins. A maximum width of 20 feet is attained, the vein matter being a brown, soft, decomposed mixture of quartz and argillite. On the well-defined hanging wall is a 4-foot pay streak panning well in free gold, while the whole width prospects more or less. Certain parts of the rock outside of the hanging wall also show good values. On the foot wall lies a 5-inch streak of black decomposed sulphides. The developments consist of a 90-foot crosscut about 70 feet below the croppings, and a 70-foot winze sunk on the pay shoot below this level. The prospect seems promising, although it is probable that the ore will become more base as the present workings are deepened.

Quebec claim.—The ridge between Clear Creek and Olive Creek contains many strong quartz veins. About 3 miles west of Alamo is the Quebec, which is rather extensively developed and is said to be a very promising property. It has recently been sold to a company that proposes to erect a mill on the same. The Quebec is developed by three tunnels, the uppermost being 750 feet above Clear Creek, and drifted 240 feet on the vein; the second tunnel, 120 feet lower, is run on the ledge for 500 feet; while the lowest is a crosscut, just started, 400 feet below the croppings. The vein, which crops prominently and strikes northeasterly, consists of the usual brecciated argillite, cemented by quartz, which often shows pronounced comb structure. The width is 10 feet, sometimes increasing to 30 feet. In the vein matter of altered argillite occur spots and streaks of a green, earthy mineral, which is finely divided chromium mica (fuchsite or mariposite). It is claimed that there is a pay shoot, 4 feet wide, of good milling ore, containing, in places, bunches of richer ore with visible gold; some of the latter ore is reported to have been shipped.

Other claims.—Near the Quebec is the mine of the Scandia Tunnel Company, which is working on a long crosscut tunnel running in under the ridge to top ledges cropping near the summit. On the north side of the creek, near the junction of Clear Creek and Lightning Creek, is the Wilson vein, its croppings showing prominently 100 feet above the creek. The croppings, which are traceable for several hundred feet, with a direction of N. 35° E., consist of the usual zone of crushed argillite cemented by quartz. Green stains of chromium mica are common in the slate inclosed in the vein. The developments consist of a tunnel giving a depth of 70 feet.

On the south side of Clear Creek, at Alamo, a 450-foot tunnel, 25 feet above the creek, has been driven by the St. Anthony Mining Company. In this distance the management claims to have crosscut four large lodes, 60, 50, 152, and 35 feet wide. It appears very clear that these "lodes" are nothing but slightly mineralized strata of the argillite cut about perpendicular to the strike. The croppings above the tunnel show nothing but heavy benches of siliceous argillite with northwesterly strike and steep southwesterly dip. The rock throughout the tunnel is soft, crushed, and decomposed—a light-gray argillite filled with light-green streaks of earthy chromium mica, and in places cut by seams of quartz, calcite, and pyrite. A great number of assays have been made, and all are said to show a minute quantity of gold. The occurrence is of interest as showing an extensive impregnation of the country rock by auriferous solutions.

Conditions similar to these appear to occur in Nevin's claim, near the town of Granite, where a 200-foot tunnel has disclosed soft slate filled with little bunches and lenticular masses of quartz and calcite and small seams of pyrite; also the same chromium-stained green spots in the slate so often noted from this region. This is probably also a case of impregnation along certain strata of argillite. Small assay values are constantly obtained.

Strasburg claim.—This is located 1 mile above Alamo, on the west side of Olive Creek. The developments consist of several shorter tunnels and a 500-foot crosscut from the creek level at an elevation of 4,950 feet, not yet completed. The steep slopes, adjoining a gravel flat in which Olive Creek flows, consist of very decomposed siliceous argillite without clearly defined strike, and contain dikes of a likewise soft and decomposed porphyry, probably a granite-porphyry. There are two adjacent veins, one of which shows an outcrop of quartz with argillite fragments, 300 feet above the creek and 25 feet across. This is reported to average $5 in gold, one 4-foot streak showing better values. An intermediate tunnel exposed both veins, which are here of only moderate size; the one carrying the big outcrop is here less than 1 foot wide.

Yellowstone and Van Anda claims.—Across Olive Creek from the Strasburg is the Yellowstone, opened by a 600-foot crosscut. Several other lodes are found on that side of the creek, all having a northeasterly strike.

Two miles farther up Olive Creek, also on the west side, are the Van Anda claims, which are said to cover strongly pronounced croppings similar to the Strasburg and other argillite veins. The developments are not very extensive.

Little Giant mine.—At the foot of Greenhorn Mountain, near the head of Spring Creek, is located the Little Giant mine. The elevation is 5,911 feet. The road from Alamo, which is 6 miles distant, follows up Spring Creek through thick timber. Though placers were formerly worked in this creek, no quartz vein had been found until in 1898, when this mine was uncovered. The following year it was sold for $30,000, according to report; developments were begun and a 20-stamp mill was ordered. On account of various financial vicissitudes, all work was suspended in the summer of 1900, though later on work in the lower tunnel has been resumed.

The developments consist of a 40-foot shaft on the croppings (elevation 6,240 feet) and an upper tunnel 80 feet lower down; this is a crosscut for 300 feet and the ledge has been drifted upon for 200 feet. The lower tunnel, 350 feet below the croppings, is at present 850 feet long, but had not, when visited, reached the vein.

Along Spring Creek, the prevailing rock is serpentine and diorite; but at the mill is a contact, and the whole east side of the gulch is composed of dark-gray, massive argillite. The vein strikes due northeast, while its dip is as yet unknown. The croppings do not show prominently, but are well exposed by means of trenches. Good pay is reported all along the surface for 600 feet northeast. Toward the southwest the serpentine contact is not far away and the vein does not seem to be traceable across it.

In the upper tunnel the usual character of veins in argillite is shown. It is a belt of crushed argillite, in places reaching 20 feet in width, filled with quartz seams and locally crushed and clayey. Much of the quartz is stained green by chromium mica, the metal probably being derived from the adjoining serpentine. No pyrite is visible in the decomposed quartz. The seams, as usual, show clearly defined comb structure, indicating deposition in open space, and the argillite is not much silicified.

The lower tunnel, as stated, has not yet cut the main vein, but has encountered two others, not known on the surface, which is covered by débris. The first of these was found 300 feet from the portal, strikes northeast, is vertical, and consists of the usual quartz-cemented argillite, 3 feet wide. It is said to carry good value. The next, 800 feet from the entrance, strikes east-northeast and dips 45° SE. It is 1 to 2 feet wide and carries much pyrite and arsenopyrite.

PLACERS.

The streams above Alamo—Beaver Creek, Clear Creek, and Ruby Creek—are filled with gravel to a depth of 15 feet and a width of from 50 to several hundred feet. All of these water courses have been washed, though few placers have records of having been extraordinarily rich. Old placers on low gravel benches are also found on Spring Creek, a mile or two below the Little Giant mine. Most of this kind of placer work has been done by Chinese. Olive Creek and Quartz Gulch are the localities reported richest. For a mile or two above Alamo, Olive Creek widens considerably, but the gravels in this flat are said to have been too deep for successful work by old methods. If found rich enough they might be successfully dredged. Quartz Gulch, coming down from the vicinity of Robinsonville, is said to have been especially rich. The gold ranges in value from $14 to $17 per ounce, the poorest quality being found high up on the creek, where much ragged quartz gold appears. On the road from Olive Creek to Robinsonville, near the divide toward Lightning Creek, a patch of rhyolite covers the slates, and on this rhyolite, at an elevation of 5,500 feet, rests a small body of auriferous gravels, which have been worked to some extent. This is another instance of the high gravels which are found in the Granite Basin about elevations of from 5,300 to 5,500 feet, and which indicate a damming by basaltic flows to this depth.

The Olive Creek mining district was organized in 1863, and in 1870 80 white men and 50 Chinese were at work. About 1873 the yield began to decline. In 1882 15 white men and 20 Chinese were at work, and the placers are reported to have yielded $13,000. Since then the production from this source has steadily diminished, and at present but little placer work is being done.

GREENHORN DISTRICT.

General statement.—This district, situated in the Greenhorn Mountains, embraces an approximate area of 18 square miles, extending for 6 miles east to west and 3 miles north to south. Greenhorn Ridge forms a high backbone, with bare summits, dividing the waters of the Middle Fork from those of the North Fork of the John Day River. It culminates in Greenhorn Peak, with an elevation of 8,130 feet above the sea, situated at the head of Clear Creek. The vicinity of this peak is the highest portion of the ridge; eastward, it falls off toward Robinsonville; westward, the ridge continues with an elevation of above 7,000 feet for about 10 or 12 miles, when it gradually sinks. A prominent gap, at an elevation of 7,200 feet, exists in the eastern part of the ridge at the head of Boulder and Desolation creeks. As may be expected, the climate is rough and means of communication are scant. One principal wagon road leads up Clear Creek from Alamo, climbing a long ridge which finally reaches the summits and the gap mentioned by way of the Ben Harrison and Potosi prospects. Another road leads up to the Intrinsic group from near Robinsonville. West of Boulder Creek there are no roads and few trails. Aside from a few sharp peaks the summit of the ridge is rather flat, and is sometime half a mile or a mile broad, sharp ravines being incised on both sides.

Geologically, Greenhorn Ridge is composed of an oblong area of older rocks, surrounded on the north and south at a lower level by lava flows in which the North and Middle Forks of John Day River have cut their broad canyons. The older rocks extend eastward with lower elevations, and connect with Bald Mountain and the Elkhorn Range. Westward their extent is not known, though they are ultimately submerged below basalt; but there are considerable areas of diorites and slates in the lower drainage of the Middle Fork and on Desolation Creek. The larger part of the ridge consists of diorite, gabbro, and serpentine, with minor areas of contact-metamorphic slates. The ridge north of Clear Creek consists of hard, dark-gray to light-gray diorite and quartz-diorite. A short distance above the Potosi contact-metamorphic slate with varying strike (at the road the strike is east-west, dip vertical) begins, but is not extensive. It is cut by areas of dark-green serpentine weathering brown. At Boulder Gap the rock is a light-gray granodiorite or quartz-diorite. This continues down Boulder Creek on the east side as far as the Ornament claim, and still farther down on the west side, when serpentine and slate again begin. The same rock forms the broad and high ridge east of the gap, in which but few prospects are known. Patches of basalt cover the ridges in places, especially west of the gap.

The deposits are fissure veins carrying their value chiefly in silver, thus differing from the auriferous character ordinarily found in this region. Few of these deposits can be ranked as mines, inaccessibility and expense of treatment having retarded this section very much. A few of the claims, among them the Ornament, Tempest, Ruby, Carbonate, and Potosi, were visited; regarding some of the others reliable information has been gathered.

The silver veins of the Greenhorn Mountains have been known at least twenty years, and smaller developments are noted in the Mint reports of 1890 and 1891. Lately they have been prospected more extensively.

Rich silver ores have at intervals been shipped to the smelters in small quantities from these prospects, the Tempest being the largest producer, with 180 tons. The expenses are very high, so that ore, to be profitably shipped, must contain at least $25 per ton. The ore must be hauled 35 miles over difficult roads to Sumpter, loaded on cars there, and reloaded on the main line at Baker City. Further, they are not very desirable smelting ores, containing no lead, but often, on the contrary, arsenic and zinc in quartzose gangue.

The ore consists of two classes: (1) Pyritic ores with pyrite, arsenopyrite, and zinc blende. These occur as seams and veinlets in large veins of altered quartz-diorite. (2) Tetrahedrite ores, consisting of irregular masses of this mineral in wider bodies of quartz. The developments are scarcely extensive enough to prove whether large masses of low-grade ore occur. If so the first class can, no doubt, be economically concentrated, but to the second this procedure is only applicable with considerable loss on account of the soft character of the tetrahedrite, which is apt to cause rich slimes.

Description of veins.—Near the eastern end of the high ridge are several important groups of claims.

The Intermountain group (also called the Snarr), about 3 miles due west of Robinsonville, was located in 1890 and is said to show three well-defined quartz veins in diorite and greenstone. The strike is northeast, the dip nearly vertical. The ore consists of quartz gangue with tetrahedrite, rich in silver, and the pay streak is reported 3 feet wide. Ore to the value of $5,000 has been shipped.

The Intrinsic group, in the same vicinity, also known as the Ordway mines, is said to contain two veins converging to one at a depth of 100 feet. The developments consist of a tunnel 800 feet long. The ore is similar to that of the Intermountain, consisting of quartz gangue with irregular grains of tetrahedrite.

A few miles farther west, on the Summit plateau, is the Morris, likewise containing rich tetrahedrite and credited in the Mint report of 1891 with a production of $15,000 in silver and $3,400 in gold. A short distance northwest of the Morris are the Mountain Consolidated, Potosi, and Savage claims, at an elevation of 7,200 feet, all fissure veins in fine-grained diorite, and developed by short tunnels. The strike of the Potosi vein is N. 20° E., the dip 40°E. The gangue is quartz, in part with comb-structure and sometimes frozen to the walls. The width is moderate and the ores consist of pyrites, arsenopyrite and zinc blende, with a little chalcopyrite and bornite. The values are chiefly in silver, but with a little more gold than is usual in the Greenhorn veins. In 1900 about 80 tons of ore were shipped to smelter, and reported to contain $53 per ton. One mile northeast of the group is the Ben Harrison, carrying similar ores.

At Boulder Gap (elevation 7,200 feet) is the Carbonate vein, striking northeasterly and developed by a short tunnel. The country rock is the quartz-diorite, close to the serpentine. The ore consists of fine-grained quartz, with some dolomite or magnesite, and containing arsenopyrite and pyrite, as well as stains of green chromium mica.

Going down Boulder Creek southward from the gap, the Ruby and the Chloride are passed on the right. Both are developed by a few hundred feet of tunnels, strike northeasterly, are contained in quartz-diorite, and present a general resemblance to the Tempest described below. Minor shipments of ore have lately been made from the three last-named claims. The ore consists of arsenopyrite, pyrite, zinc blende, and a little galena, all occurring in many small veinlets of comb-quartz in a diorite which is bleached by the development of sericite and calcite.

One mile down from the gap are the Tempest veins, at an elevation of 6,500 feet. The developments consist of several short tunnels. From this mine a considerable quantity of ore has been shipped, yielding a profit in spite of very adverse conditions; shipments are reported to aggregate 180 tons. There are 5 veins cropping in quartz-diorite, striking N. 35° E. and standing nearly vertical. The veins are from 2 to 4 feet wide and consist of altered sericitic country rock traversed by small stringers and streaks of comb-quartz, with arsenopyrite, pyrite, and zinc blende, the value being chiefly in silver, with very little gold.

Still half a mile farther down the gulch is the Ornament, developed by three tunnels, aggregating several hundred feet. The vein is located near the contact of slate and serpentine with quartz-diorite. The ore is similar to that of the Tempest. Small shipments were made as early as 1890.

ROBINSONVILLE DISTRICT.

GENERAL FEATURES.

A broad shoulder of Greenhorn Ridge projects eastward beyond Robinsonville, its flanks deeply scored by ravines leading down to Burnt River on the east and to the two forks of the John Day on the north and the south. The elevation at Robinsonville is 6,200 feet.

The rocks exposed are the same as in the Greenhorn Mountains; that is, they comprise large areas of serpentine, gabbro, diorite, and quartz-diorite. Included slate masses are not common. Near Robinsonville the serpentine occurs in extensive areas, and probably results from alteration of olivine-gabbro. All of the rocks mentioned are believed to form one series, and they can scarcely be separated on the map. They appear to be different facies of one intrusion and are more recent than the argillites into which they are intruded. Robinsonville is an old, celebrated placer camp, but at present consists only of a few dilapidated log cabins.

QUARTZ VEINS.

Since early days the presence of gold-bearing veins was known, and they have been worked intermittently. On the whole the deposits seem to be pocket veins, and many rich little quartz chimneys have been found in the flat on which the town is situated. In contrast to the other veins on the Greenhorn Mountains, these are auriferous, and present such curious features as the association of native gold, galena, and dolomite.

The Spero, at Robinsonville, is in serpentine, strikes N. 30° E., is 10 to 15 feet wide, and is composed of massive white quartz.

The Virginia, one-fourth mile north of Robinsonville, in coarse, partly crushed gabbro, has a shaft 160 feet deep. Long ago a pocket of $20,000 was found in it, but more recent prospecting has failed to produce more.

In the Morning Glory, one-third of a mile northwest of Robinsonville, the vein strikes due north and dips 80° W. The gangue is a normal comb-quartz with free gold. Some of it has been sacked for shipment. Several small pockets have been found close by.

The Junebug, one-fourth of a mile southwest of Robinsonville, in serpentine, has a northwesterly strike. The vein contains much dolomitic carbonate, and also galena, together with free gold. The developments consist of two small shafts. Fifty tons of ore, worth $25 per ton, have been milled.

The Don Juan and Phœnix are located about 1 mile south of Robinsonville, on the headwaters of Burnt River. The ore consists of coarse, granular dolomite, with a little quartz and galena. It contains abundant high-grade gold, intergrown as small grains with the carbonate. The mine has an 80-foot shaft, 1,000 feet of development, and a 10-stamp mill. A pay shoot, 30 feet long, 4 feet wide, and containing about $36 per ton, was found here, but did not hold out in depth.

The Banzett is located 2 miles west of Robinsonville, on the headwaters of the Middle Fork of John Day River, at an elevation of 6,350 feet. The vein is in a soft, decomposed, serpentinoid rock, and is developed by a shaft 100 feet deep, and a tunnel 1,000 feet long 100 feet below it. The gangue is normal vein quartz, containing a little galena and chalcopyrite, and is said to run $60 per ton in gold. Eighty-three tons of ore are said to have been shipped in 1898.

The Diadem vein is situated a short distance north of the Banzett and 100 feet higher up. The vein strikes east-west and is developed by smaller shafts and a tunnel 550 feet long. It is intended to extend the latter 200 feet, giving a vertical depth below the croppings of 425 feet. The gangue is quartz; the principal ore is mineral galena, often in considerable masses, together with a little chalcopyrite. Both are rich in free gold. The vein is claimed to be 20 feet wide, one rich streak assaying $200 per ton. A shipment of 16 tons in 1900 is reported by the officers of the company to have netted $1,819.

In Quartz Gulch, leading down from near Robinsonville to Olive Creek, are several noteworthy prospects. The three Golden Gate claims are located 1 mile north of Robinsonville, and show a heavy vein of white quartz with little sulphurets, exposed by 500 feet of crosscut and 100 feet of drifts. Serpentine and gabbro form the country rock. The strike is due north, the dip 60° E. A total thickness of 47 feet of quartz is claimed to contain $6 to $7 per ton. A footwall streak 4 to 5 feet wide contains the best values. Another and parallel vein, dipping west, courses a short distance to the east, and is said to assay from $8 to $24 per ton.

A little lower down on Quartz Gulch are the Belcher claims, which probably do not cover the same vein as the Golden Gate. Still farther down is the Kelly group, with over 400 feet of developments. The country rock is here a tuffaceous slate cut by dikes of granite-porphyry. On one of these dikes the Imperial claim is located. Quartz Gulch is known to have been very rich in gold in early days, and the locality would seem to be a good one for prospecting. Several other claims, not visited, are located about 1 mile east of Robinsonville, on the Bonanza road. Cinnabar is reported to occur in a vein or seam near Robinsonville.

About 5 miles south of Robinsonville, at an elevation of 5,100 feet, on the road to Austin, is McNamee Gulch, reported very rich in early days. A $14,000 nugget was found here. Some prospecting for quartz has lately been done in this gulch, resulting in the location of the Pine Tree group of quartz veins. The country rock is serpentine, gabbro, and diorite.

PLACER MINES.

Robinsonville Gulch and several other small streams as far south as McNamee Gulch have been extensively worked for placer gold, and some work of this kind is done at the present time at the last-named locality. The gravels were shallow, resting in flat gulches, and were rich in high-grade gold.

UPPER BURNT RIVER VALLEY AND BONANZA DISTRICTS.

GENERAL FEATURES.

In many respects the upper drainage basin of Burnt River is very similar to that of Powder River. The lower Burnt River Valley extends from Bridgeport (elevation 3,400 feet) to a point 20 miles west of it (elevation 3,900 feet), and has a width of up to 1 mile of alluvial and bench lands, the former covered with meadows or alfalfa fields. The ridges rising south of this valley are smooth and bare, patches of timber occurring only in some of the gulches. A few miles above Hereford, the principal settlement in the valley, the river enters a sharply cut canyon, continuous for 15 miles to the upper valley, the lowest elevation of which is 4,100 feet. This valley is an almost circular depression, 5 miles in diameter, its gravelly bench lands surrounded by gently sloping ridges rising to maximum elevations of 6,000 feet. This region, in the heart of the Blue Mountains, is covered with dense forest and is abundantly watered by a number of creeks, all converging toward the lower end of the valley. Much of the timber is excellent yellow pine.

GEOLOGY.

The older rocks are found only in the upper part of the valley, while the Neocene lavas are developed to an enormous extent in the lower drainage area. Among the older rocks argillites predominate. Such rocks make up the larger part of the long ridge separating the upper Burnt River or Clifford Valley from the Sumpter Valley. As usual, the rocks vary from fissile clay slates to dark siliceous cherts. Similar rocks are exposed on the road from McEwens to Hereford, on the north side of the ridge, below the andesite cap covering the summit. In places slightly schistose greenstones are interbedded in the sedimentary series. At the head of Gimlet and Camp creeks similar siliceous argillites form the divide. At Bonanza mine fissile black clay slates appear. At Winterville, close by the placer diggings, is found a stratum of limestone 300 feet thick, which contains unmistakable round crinoid stems. The strike of this somewhat crystalline limestone is N. 70° W. At Bonanza mine the slates strike east-west and dip 80° S. This is evidently the prevailing direction, and it is the same also in the Sumpter district. The crinoid stems of Winterville form the only cue to the age of the whole series. It may be surmised that it belongs to the Carboniferous division of the Paleozoic.

The argillites contain few intrusive bodies. In the foothills south of Sumpter Valley, near Stoddard mill, a dark granodiorite appears from the gravel flat up to an elevation of 4,900 feet. Above this follows apparently contact-metamorphosed argillite, capped by andesitic breccia. Serpentine, forming an extension of the Robinsonville areas, crops in a small area just above the town of Geiser, close to the Bonanza mine, and also a mile below it at the Winterville diggings, here associated with other, not determined, chloritic greenstones.

Neocene lavas cover an exceedingly large area south of Clifford. Rhyolites, andesites, and basalts are represented, the rhyolites being, as far as can be determined, the oldest.

Normal lithoidal rhyolite covers the whole divide between Powder and Burnt rivers from a point south of Pleasant Valley and southeast of Baker City for 15 miles westward, to the vicinity of Hereford, where it is covered by andesitic breccia. This rhyolitic ridge attains an elevation of from 5,500 to 6,500 feet. The rock descends on the north side of the ridge to the level of the basaltic flows (elevation 4,700 feet). On the south side it reaches down to Hereford Valley and appears again in the ridges south of Burnt River. The general form of this great rhyolite mass is that of a dome sloping gradually from an elevation of 6,000 feet to 4,300 feet. From this point a sharper slope of erosion sets in to the level of the gravel benches at Hereford. Closely crowded gulches have been cut in this rhyolite dome to a depth of from 1,000 to 1,500 feet. Thinner rhyolite flows appear again in the bottom of Clifford Valley; for instance, at the junction of Pine and Camp creeks, 2 miles northwest of Clifford.

Dacite was observed closely connected with rhyolite on a small tributary of Burnt River, 4 miles north of Hereford, on the road from that place to Sumpter.

Andesite and andesitic breccia cover a very large area. Beginning on the divide north of Hereford, a thickness is exposed of 300 feet on the Powder River side and 1,000 feet on the southern slope. Near the summit, well-stratified volcanic tuffs and breccias are exposed. The latter contain angular fragments both of dark pyroxene-andesites and lighter hornblende-andesites. This area continues westward practically to the slopes of John Day Valley. The breccias appear on the floor of Clifford Valley just east of the place of that name and are here covered by bench gravels, and the same breccias extend up to the Bonanza mine. Practically the whole divide between the Middle Fork of John Day and Burnt River, forming flat-topped, forested plateaus reaching 6,000 feet in elevation, is composed of this breccia. Overflowing, the same lavas once filled the Middle Fork of John Day down to Susanville to a depth of 1,500 feet.

The breccia consist of angular fragments of normal andesites of varying appearance. Some are dark gray, others brownish or black; many fragments are vesicular. All of them are hypersthene-augite-andesites (pyroxene-andesites), and sometimes those of lighter color contain also hornblende in black needles.

Basalts are less abundant. Below Hereford, in the lower valley, normal olivine-basalts, weathering gray, cover the rhyolite. Near Austin, and above that place on the headwaters of the Middle Fork, fine-grained glassy basalts cover the andesite.

The gravel deposits found along Burnt River Valley are of several different kinds. Such deposits as may have accumulated before the volcanic period, and are, therefore, Neocene or Eocene, have mostly been eroded or covered by lavas. A few of this interesting class have been exposed by placer mining and are described under the heading "Winterville placers" (p. 703). In areal extent they are insignificant.

The damming of the lower Burnt River Valley below Bridgeport by rhyolitic flows induced the accumulation of extensive gravel deposits above. Near Hereford are two of these benches at 400 and 600 feet above the valley bottom, which is covered by alluvial deposits. They consist of coarse, well-washed gravels of rhyolite, quartz, and metamorphic rocks. The age of these bench gravels is assumed to be late Neocene (Pliocene).

Similar damming produced similar results in the upper or Clifford Valley. Wide benches are covered by coarse, well-washed gravel, resting on argillite, rhyolite, or andesite. These are excellently shown on the Sumpter road. The highest terrace slopes from an elevation of 4,550 feet down to 4,300 feet in a distance of 2 miles. A sharp escarpment separates this from a second bench 100 feet lower and 1 mile wide. Finally, a last escarpment of similar height carries one down to the alluvial flats along the river.

No indications of a former glaciation have been found in this drainage basin.

QUARTZ VEINS.

Though some gold-quartz veins are known from the head of Gimlet Creek and other places on the divide toward Granite Creek and Sumpter, the only place in which they appear strongly developed and in which they have been mined with success is the Bonanza district. The quartz veins of Robinsonville, which to some extent belong in this drainage area, have been described under separate heading.

Bonanza mine.—The Bonanza mine is situated about 10 miles west of Sumpter, on the headwaters of Burnt River, at an elevation of 5,140 feet (lowest floor of mill). The first location is said to have been made in 1877 by a pioneer prospector named Jack Haggard, who sold it in 1879 for $350 to the Bonanza Mining Company. In 1892 the mine was bought by Geiser Brothers for a reported sum of $3,000 and worked by them until 1898, when it was sold to the present owners, a Pittsburg, Pa., corporation, for a price believed to have been $500,000. The production before 1892 was inconsiderable, though extending over a series of years. Geiser Brothers are supposed to have taken out several hundred thousand dollars. When sold, $300,000 were believed to be in sight. Since 1898 at least an equal amount has been extracted, making the total production well up toward the million-dollar mark.

A 40-stamp mill and concentrator treat the ore. During the fall of 1900 only 15 or 20 of these were dropping.

The developments consist of two tunnels, the upper 1,400 feet long and 230 feet below the croppings, the lower 1,600 feet long. The latter is the main adit, 338 feet below the croppings, and a shaft is sunk in it 600 feet from the mouth to a depth of about 200 feet.

Further sinking is being carried on at the present time. In all, there are probably 10,000 feet of development work.

The country rock is a fissile black clay slate, striking nearly due east-west and dipping 80° S. A little above the town of Geiser, at the mill, this slate is cut by a considerable belt of serpentine. The same rock appears again below Bonanza, toward the diggings of Winterville. To the north and east the serpentine and clay slate are covered by andesitic lavas. The veins appear to be exclusively contained in clay slate. The Bonanza vein, cropping on a hill 500 feet above the mill and about half a mile northeast of it, strikes N. 50° W. and dips steeply southwest. It is traceable on the surface for about 2,500 feet northwest of the main tunnel, but is then covered by an extensive lava area, referred to above.

The outcrops are neither wide nor conspicuous, and have been stoped to the surface in several places. The vein appears as 1 to 3 feet of quartz between walls of decomposed slate. In depth it widens enormously in places.

Permission to visit the mine below tunnel level was refused. The following data relating to the underground works were obtained from several persons well acquainted with the mine, and are believed to be mainly correct:

The ore consists of quartz containing free gold and sulphurets and has considerable similarity to that of the Red Boy mine. The ore body as a whole forms a mass of clay slate traversed by quartz veins and seams of all sizes. The gold is low grade, being about 600 fine, or worth $11.50 per ounce. Something like 70 per cent is free, though it is said that as the depth is increased more concentrates and less gold are obtained. The concentrates are said to vary from $20 to $60 per ton, chiefly in gold.[1] The average ore is believed to run from $7 to $12 per ton, but lenses of ore 8 to 16 inches wide have been mined which ran as high up as $1,400 per ton, and several hundred tons are said to have yielded at the rate of $100 in free gold per ton.

Though the pay streak averages only 5 to 6 feet, it is swelled in places to 40 feet by the appearance of a vast number of quartz stringers.

The upper tunnel, 1,400 feet long, is said to have encountered two pay shoots, each 200 to 300 feet long and up to 6 feet wide. Still farther in, a third pay shoot was found, which extended only 30 feet above the tunnel level. It was 40 feet long and 5 feet wide, and averaged $15 per ton. An intermediate level, sunk 40 feet from the middle shoot, was extended for 480 feet in very poor ore.

The lower tunnel, 1,600 feet long, encountered a small shoot below the first one in the upper tunnel and was then driven for the rest of the distance on a poor streak of quartz near the hanging wall. A crosscut in the foot, 500 feet from the portal, had failed to disclose anything of value; likewise a crosscut near the end. It seemed as if the mine was worked out when the owners were prevailed upon to crosscut at other places in this adit. These crosscuts, from 30 to 120 feet long, into the foot-wall side disclosed the presence of a magnificent lenticular mass of ore of a maximum width of 40 feet and 800 feet long.

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[1] A sample gave 0.84 ounce gold and 0.76 ounce silver per ton.

Regarding the conditions below the tunnel level but little information is to be had. According to latest reports fine bodies of ore have been developed below the second shaft level, and the production, which had been declining before, rose to something like $50,000 per month.

Other mines and claims.—Near the town of Geiser are located several mines and prospects which, though not as yet producing, deserve mention. Among these is the Richmond, a vein parallel to the Bonanza and southwest of it, which is developed by a Canadian company and on which a 10-stamp mill has just been erected. The mine is developed by a shaft 300 feet deep. The Keystone Belle covers the extension of the Bonanza and is now being prospected. The White Elephant is still farther to the southwest and is being developed by a tunnel. In character all of these are similar to the Bonanza.

PLACER MINES.

Many of the creeks in the Clifford Valley have been profitably worked and some have been rich. Among them are, from west to east, Bennett Creek, Camp Creek, Gimlet Creek, and Three Cent Gulch. Placer work has been done in this valley since early days and a production is still maintained.

The gravels washed range in age from Neocene or Eocene to the most recent Pleistocene. The gold is sometimes extremely coarse, as in the Winterville placers, or very fine and floury, as in the ordinary bench gravels of Camp Creek. The fineness is remarkable, some of it reaching $19 to $20 per ounce.

Placer mining is carried on in Three Cent Gulch by Sullivan & Co., who operate one hydraulic jet with 400 miner's inches of water. Gimlet Creek has been worked extensively at the forks above the Sumpter road, and it is said that this locality has produced $100,000. In Camp Creek, at the junction of Pine Creek, 2 miles northeast of Clifford, are the Hindman placers. Here a low bench gravel is worked just above the creek bottom, at this point 200 feet wide. The 10-foot-high bank of well-washed gravel rests on rhyolite. About 70 feet above the creek the heavy bench gravels begin which skirt the eastern side of Clifford Valley. The gold is rather coarse, and has a fineness of 919. It is accompanied by much magnetite and ilmenite, the latter in beautiful crystals. There are also some garnets and zircons in the black sand, as well as epidote. Mr. Hindman states that about half an ounce of platinum is obtained at each clean-up. This is the only occurrence of platinum thus far known from the Blue Mountains. The heavy bench gravels are, as a rule, too poor to pay for washing, but contain some flour gold with the fineness of 970.

The placers of Winterville and Parkerville are unusually interesting. The Winterville diggings are located on Bennett Creek, three-quarters of a mile south of the Bonanza mine and at an elevation of 4,900 feet. The placers have been worked intermittently for many years and have doubtless yielded a large sum in aggregate. According to Mint reports they produced $25,000 in 1889, $8,300 in 1890, $1,900 in 1891, and $1,400 in 1892. During 1900 they were in active operation and the production is supposed to have been over $20,000. The water is obtained from the Mann ditch, which, with an aggregate length of 30 miles, taps the headwaters of Clear Creek and Olive Creek and is said to have a capacity of 5,000 miner's inches.

Near the Bonanza mine Bennett Creek flows on andesitic breccia, though immediately east of the creek the high slate hills of Bonanza project from below the volcanic flows. At Winterville the creek leaves the andesite and for half a mile below flows over bed rock of slate and serpentine. In this distance the gravels along the creek bed have been worked. The gravels washed at present are found about the level of the creek and on its western side. The area which thus far has been hydraulicked comprises about 3 acres, the banks being from 15 to 20 feet high. The bed rock is a serpentinoid greenstone of uneven surface. A north-south fault in the bed rock has been exposed 100 feet long and showing a scarp 30 feet high which dips 60° E. The pay gravel, resting on the bed rock, is from 3 to 10 feet thick, not very coarse, and sometimes cemented. It contains pebbles of serpentine, quartzite, slate, and quartz. Above this rest 15 feet of clayey beds with small strata of coaly material. Above this follows 2 feet of hard, cemented gravel, covered by andesitic tuffs and breccia. The gold, found chiefly on the bed rock, is extremely coarse, the pieces ranging from 0.05 ounce up to 15 ounces in weight, but at the same time very well washed. Most of the nuggets have an oblong, flat shape. The fineness averages 900. This interesting deposit was clearly formed before the time of the Neocene andesitic eruptions and must be of Eocene or early Neocene age. The high bed-rock hills rising on the southwest side and the general configuration of the country indicate that it was a narrow gulch of an upper drainage system which had a general east-west direction across the present creek. The increasing height of the banks will soon interpose difficulties for continued hydraulic work. The bed rock seems to pitch downward at present and at its deepest point probably lies below the level of the creek. Inclines sunk will probably develop a heavy flow of water. On the other hand, if the channel came down from the west, and there is little doubt of this, it would seem feasible to follow it up by a drift from the present bed-rock level.

Two miles west of Winterville are the Parkerville diggings, which are reported to have produced $150,000. They are said to be similarly situated and may represent the continuation of this channel. The continuation of this channel east of Winterville has not been found and the probability is that it would be considerably below the present level of the valley.

CHROMITE.

Heavy float of chromite was noticed at the Winterville placers; the serpentine in this vicinity must contain a pocket of this mineral.

CHAPTER V.

DETAILED DESCRIPTIONS OF MINING DISTRICTS (CONTINUED.)

SUSANVILLE DISTRICT.

GEOLOGY.

The Susanville district is situated on the Middle Fork of John Day River, 30 miles west of Sumpter in air line, though by wagon road the distance is about 55 miles. From Austin the road follows the Middle Fork down to Susanville, which has an elevation of 3,500 feet. Heavily forested ridges rise on both sides of the little gravel flat on which the town is located. About 7 miles northeast from the river the Greenhorn Ridge rises to over 7,000 feet, so that the slopes down to the river are not very steep. On the southwestern side of the river the configuration is more irregular and the ridges attain a height of only about 5,000 feet.

The geological features are as follows: The Middle Fork has cut down through the basalt flow which in Miocene times filled the valley, and the road from Austin to near Susanville is entirely in this lava rock. At Susanville the old rocks of the Greenhorn Ridge reach down to the river and across it, but only, it is believed, for a short distance. These old rocks also continue down the Middle Fork until below the mouth of Big Creek, or 6 miles below Susanville, where, according to information, the lavas again begin.

A fissile, dark-gray clay slate is the principal formation exposed above and below Susanville. At the Badger mine a strike of N. 70° E. and a southerly dip of 65° was noted; one-half mile below the mine, in Elk Creek, the strike is N. 80° E., and 1 mile below Susanville it is S. 85° E. with steep southerly dip. Thus, in general, the strike of the series is east-west and similar to that of Sumpter. Smaller dikes of aplitic rocks cut the slate between the town and the Badger mine. In Elk Creek, 2 miles above the river, at the Otter mine the slate is adjoined by serpentine, which continues up Elk Creek, mixed with much greenstone (diabase or gabbro) up to near the head of the creek, when a high ridge of granitic rock appears. This is probably the continuation of the central area of quartz-diorite mentioned in the description of the Greenhorn Mountains. Dikes of basalt are said to break through this granitic rock and on the flat summit is a small table of basaltic lava. West of the head of Elk and Deep creeks the high ridge gradually sinks.

QUARTZ VEINS.

The placers of Elk Creek have been worked since 1864 and are described below. Prospecting for quartz began as early as 1869, when Mr. Cabell's pan-amalgamation mill was built on Elk Creek 2½ miles above its mouth. Ore from a vein called the Monumental was worked there, yielding, according to Mr. Haskell, $15,000. Several other prospects were then in active operation, but for many subsequent years little or nothing was done, until recently, when renewed prospecting has given good results. While there are some narrow quartz veins with products of free gold, the bulk of the ore consists of heavy sulphurets, which contain little or no free gold. The values are chiefly in gold, though the rich shipping ore also contains much silver. The total production from the quartz veins probably does not exceed $100,000. This is to some extent due to the inaccessibility of the district, making shipping expenses extremely high. Apparently there are several claims of considerable merit.

The Badger mine is at present the most important producer. Its vein was known as early as 1869 and was worked under the name of the McQuade ledge. In 1870–1874 some free gold was extracted from the decomposed croppings. This ore yielded $26 per ton in arrastre, the gold being 691 fine. Later on a 10-stamp mill with concentrators was built on Elk Creek below the mine, but the ore was soon found unsuited to such treatment. At present the rich ore is sorted and shipped to smelter. It is clear that the values must exceed $30 per ton to make the transactions profitable. The developments consist of an incline shaft 250 feet deep, with drifts and tunnels aggregating 1,500 feet. Apparently there is an excellent chance for a deep tunnel from Elk Creek.

The Badger is located 400 feet above Elk Creek, 2½ miles northeast from Susanville, at an elevation of about 4,300 feet. The country rock is slate. The vein strikes a little north of east and dips 60° to 70° S. Though this is about the same direction as that of the slate, it is easily seen that the deposit is a fissure vein, for the slate is cut near and in the vein by a great number of parallel quartz seams (Pl. LXVII) perpendicularly to the schistosity. The first-class ore consists of a massive irregular mixture of sulphurets; pyrite, arsenopyrite, and zinc blende make the bulk, together with a little galena, chalcopyrite, and tetrahedrite.[1] The shipping ore always contains galena. On the dump are several hundred tons of second-class ore, among which is noted masses up to 2 feet in diameter of pyrite and arsenopyrite. Other parts of the second-class ore consist of veinlets of quartz in argillite, with a little pyrite, arsenopyrite, and zinc blende. The adjoining argillite, aside from a little pyrite contained in it, appears entirely fresh. The surface ore contained some free gold down to a depth of 25 or 50 feet.

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[1] A sample of shipping ore containing tetrahedrite was found to contain 1.04 ounces gold and 909.08 ounces silver per ton.

The Stockton, prospected by a 200-foot shaft, adjoins the Badger and is supposed to cover its extension.

On Elk Creek, below the Badger mine, is the Bull of the Woods group, with the Otter as one of the principal claims. The Otter vein, carrying heavily sulphureted ore, is located in serpentine near the slate contact and is developed by a 600-foot-long tunnel, above which much ore is said to have been stoped. The ore contains dolomite or magnesite, together with pyrite, arsenopyrite, and a little galena. It contains both gold and silver.

The Gem vein, 2 miles above the Badger, on Elk Creek, was worked to some extent in early days. The quartz contained free gold at the rate of $6 per ton, and the heavy sulphides assayed $35 in silver and gold, according to Mr. Haskell. The vein is noted for a considerable percentage of copper. At Elk City, 6 miles above Susanville, some prospecting for quartz has been carried on. Between Susanville and the Badger mine the slate contains several narrow quartz veins in which pockets are sometimes found. Among these is the Skyscraper, located three-fourths of a mile from town on the ridge west of Elk Creek.

Prospects have been found on Deep Creek and on Onion Creek, as well as on Camp Creek. The Princess vein is located near the head of Deep Creek at the contact of slate and granite. It is said to contain white quartz carrying free gold with rich sulphurets.

PLACER MINES.

The well-known placer mines of Susanville were discovered in 1864 and have been worked every season since then. Elk Creek has been the greatest producer, but Deep Creek, 1 mile below Susanville, as well as Onion Creek and Big Creek, still farther down the river, have also yielded considerably. All of these producing creeks join the Middle Fork from the north side and descend from Greenhorn Mountains. The Middle Fork itself has been worked below Elk Creek and is reported to have produced $50,000 in fine flour gold. The production during the first four years after the discovery amounted to at least $80,000 (Raymond's report for 1870). For subsequent years the scattered data are obtained in the Mint report as follows:

Production of placer mines of Susanville district, 1882–1892.

1882	$15,000
1883	25,000
1884	16,000
1889	8,700
1890	11,200
1891	7,000
1892	14,000

The total production is probably in the vicinity of $600,000. During 1900 all the creeks were worked, at least for a short season. Chinese miners were at work on Elk Creek, 1 mile above the town, with hydraulic apparatus and derricks. Drifting operations were in progress on Big Creek, 8 miles from the river. Of the creeks emptying into the river from the south, Bear Creek, 1 mile below Susanville, is being worked, and some gravel is being washed at the head of Camp Creek.

The placers of Susanville contain coarse gold of a fineness of 865; a nugget worth $480 was found on Elk Creek, another worth $625 on Deep Creek, while Buck Gulch, below Deep Creek, holds the record with an $800 nugget. Cinnabar in rounded masses up to 3 or 4 inches in diameter, intergrown with normal vein quartz, is of common occurrence on Elk Creek, but has not yet been found in place. No platinum occurs in the placers. Elk Creek has been worked continuously for about 2½ miles above its mouth. Eight miles above the mouth, at Elk City, some placer work has also been done. The pay seemed to be derived from the west side of the creek, the east fork being barren, and sometimes the gold may be traced up the hill to the quartz veins from which it was derived. These appear generally to have been narrow and of a pockety nature. The gravel is coarse and contains many bowlders of greenstone, which must be handled with derricks. Usually the bottom of the creek is level and 100 feet wide. It contains two or three channels or gutters, the rims of which were raised 1 to 3 feet above the bottom. These gutters practically contain all of the gold. The bottom of the creek is filled 10 to 20 feet deep with gravels. It has been stated above that some placer work has been done on the Middle Fork. This stream flows in a gravel-filled channel in places as much as several hundred yards wide, suitable for dredging, the depth to bed rock ordinarily being only 8 to 10 feet.

Prospecting operations for this purpose were carried on in 1898 between the mouth of Granite Boulder Creek, which is somewhat auriferous, and a point below Susanville. Many shafts were sunk, and it is believed that in favorable places along certain channels the gravels averaged 20 cents per cubic yard.

QUARTZBURG DISTRICT.

GENERAL FEATURES.

Between the Middle and South forks of John Day River rises a complex of older rocks, culminating in the round-topped Dixie Butte, which attains an elevation of 7,700 feet. It is probably on all sides surrounded by Miocene lava flows. From the bare summit of Dixie Butte, one of the landmarks of the country near which the old California trail runs, heavily timbered ridges extend in all directions. The thick forests on the north side of Dixie Butte are said to be favorite haunts of elk and bear.

The geological structure of this area is complicated, but in general the rocks consist of diorite, diabase, and other greenstones, together with serpentine, inclosing smaller areas of clay slates, the exact age of which is not known; they are, however, older than the accompanying intrusive rocks. The stage road to Prairie crosses the most easterly part of the area; imperfect exposures show diabase, porphyry, serpentine, and siliceous clay slates. But immediately at the summit, toward Prairie, basalts and andesites begin and continue down to John Day Valley. A beautiful view of the latter is obtained from this place. Between the scattered yellow pines of the park-like forest the bare volcanic slopes of the valley with its broad pastures and irrigated fields present an attractive picture, and across it toward the south rise the jagged, snow-flecked lava peaks of the Strawberry Range. On the easterly road, leading down to the valley from the summits by way of the sawmill and Spanish Gulch, first clay slates and then 2 miles of serpentine are crossed before the lava again begins.

Going up from Prairie to Quartzburg district, the road follows Dixie Creek, with its extensive and not yet exhausted placer deposits. Two miles upstream the valley widens and the covering basalt and andesite give place to an old sedimentary rock, a massive argillite. Two miles farther up, at the road junction, a narrow canyon begins, at the entrance to which is a little serpentine. The canyon, however, is cut in a normal, hard, medium-grained diorite, consisting of green hornblende and feldspar. One and a half miles still farther up, the valley opens, the diorite grows darker, and at the forks of the creek it is replaced by a diabase-porphyry. This is a very tough, dark-gray rock with dark-green crystals of augite in a groundmass of medium grain. Between Comer post-office and Present Need mine there is a great complication of igneous rocks, most of them dark-green diabase of varying grain, and also some diorite-porphyries or lamprophyric dike rocks. Similar rocks, mostly uralite-diabases, are seen on the east forks of the creek, where the copper prospects are located.

Just above the Present Need mine coarse diabase appears, in places containing small seams of dark-gray dense rock which consists of quartz and tourmaline; but these veinlets carry no ores. In the crosscut of the Present Need a 200-foot-wide belt of peculiar grayish-green, fine-grained, sometimes flinty rock appears, which seems to be diabase-tuff and allied rocks greatly altered by contact metamorphism. These are described more in detail on page 588.

The auriferous character of this area is shown by the fact that in practically all of the streams heading toward Dixie Butte placers have been worked. Important placers are found in Dixie Creek, but auriferous gravels have also been worked on Camp, Ruby, and Happy Camp creeks, draining toward the north, and Rich and Spanish creeks, toward the east.

The principal quartz veins have thus far been found on the west fork of Dixie Creek, though it is by no means improbable that discoveries will be made in other parts of the area. The veins are narrow and rich and contain heavy sulphurets in quartz gangue. The oxidized surface ore contains much free gold, but at slight depth the ores become much more base. The strike is generally north-northeast or northeast, while the dip, with few exceptions, is steep to the east.

On the east fork of Dixie Creek copper deposits of a very different type occur.

The quartz veins were discovered soon after the placers and have been worked intermittently at least since 1880. In 1900 the Present Need, owned by Mr. W. E. Gifford, who kindly furnished much information, was the only vein upon which active work was being done. The production of these quartz mines is not accurately known, but is not believed to have exceeded $100,000. Much gold was derived from the oxidized croppings, but few have been worked in depth.

GOLD-QUARTZ VEINS.

The first prospects are encountered a short distance below Comer post-office. The more important claims are located half a mile above this place.

The Present Need was located about ten years ago and has since been worked on a small scale, the ore being calcined in a kiln and then reduced in an arrastre. The developments consist of a crosscut tunnel 100 feet above the creek level and 200 to 300 feet of drifts. The country rock is a diabase, but the crosscut has exposed a narrow, greatly contact-metamorphosed series of diabase-tuff and allied rocks appearing in strata with a general east-west direction. The vein strikes N. 20° E. and dips 70° ESE. Like the other veins in the district, it is not traceable for a long distance. The width is 2 to 3 feet, indicated by fissures in the hard diabasic rocks. The ore occupies from 4 inches to 2 feet of this width and consists of solid quartz with heavy sulphurets in irregular intergrowth. There are pyrite, hard and yellow, softer yellowish-gray marcasite, and a little chalcopyrite, zinc blende, and galena. This ore is very rich and the pyrite often contains free gold. It assays from 6 to 25 ounces silver and 4 to 5 ounces in gold per ton, a total value of about $100. With the imperfect extraction used, only about two-thirds of this amount was saved.

The ore occurs in two shoots on the vein, both dipping 65° S. on the vein; the shoots are 70 feet long, and are separated by a barren zone of 70 feet.

A few hundred feet north of this mine is the old Keystone, now idle. The Mint reports show that it was worked in 1882, during which year the small veins of Quartzburg produced about $12,000, and that at that time seven levels were run. In 1883 it is reported that 500 tons of ore at $40 per ton were worked at a cost of $8.50 per ton. In 1889 the mine is credited with a production of $5,800. The vein strikes northeasterly and dips southeasterly. It is 4 feet wide between walls, the pay forming a narrow streak on the hanging, on the foot, or on both. The gangue contains much calcite, but otherwise the ore is similar to that of the Present Need.

A short distance above, the Colorado, a parallel vein, is located, and still higher up are many other claims. The Yankee Boy, on the ridge between the two forks of the creek, southwest of Copperopolis, strikes northeast and dips southeast, and is developed by 1,000 feet of tunnels. The croppings showed very heavy gold specimens, but in depth the ore became more base.

COPPER VEINS.

The active development of these claims, situated in the narrow canyon of the east fork of Dixie Creek, is of recent date, though at least one, the Standard, has been known for many years.

The Copperopolis claims are located on the west side of the canyon, 2 miles above the forks of the creek, and the croppings have an elevation of 5,250 feet. The developments consist of several cuts and shorter tunnels. An 800-foot tunnel from creek level, tapping the vein 300 feet below the croppings, was begun at the time the prospects were visited, in October, 1900. The country rock consists of a medium-grained uralite-diabase in which the vein strikes about N. 60° E., the dip being uncertain. It is traceable across a small gulch for a distance of at least 1,000 feet. The deposit forms a heavy body of tourmaline, quartz, and chalcopyrite, with a little malachite and azurite near the surface, the total width being about 75 feet, including an intercalated horse. About 40 feet of the width is copper bearing. The exact percentage of copper, sampled across the width, can not be stated; it may average 3 or 4 per cent. The ore is largely a replacement of diabase by quartz, tourmaline, and chalcopyrite, but in this rock are contained richer seams with comb-quartz and chalcopyrite. The ore is said to contain gold and silver. There is undoubtedly a large body of low-grade copper ore; though the lateral as well as the vertical extent is still unknown, the showing warrants further exploration. The concentration of the ore will be a little difficult, for the specific gravity of tourmaline (3.2) is not greatly different from that of chalcopyrite (4.2).

Somewhat less than 1 mile above the forks is the Standard copper mine, located on the east side of the creek, 300 feet above it, and at an elevation of 4,900 feet. The vein crops in a dark-greenish, altered diabase-porphyry; its strike is northeast, the dip 30° SE. The developments consist of a 100-foot-deep incline; a 300-foot-long tunnel, 100 feet below the croppings, has not yet struck this flat vein, but found a stringer of ore with about the same strike and standing vertical. The ore is here from a few inches to 1 foot wide. Both the veins are probably largely due to processes of replacement. From the shaft a few tons of chalcopyrite, also containing gold and silver, have been shipped. From the tunnel 10 tons of ore were shipped in 1900, which, according to the officers of the company, contained $34 per ton in copper, gold, and silver. There is good opportunity for a crosscut to the veins 200 feet below the present tunnel.

The ore consists of chalcopyrite, with a little pyrrhotite and smaltite. The latter mineral is a light steel-gray arsenide of cobalt and is of rare occurrence in the United States. It occurs chiefly in the vertical vein intergrown with chalcopyrite. The only gangue mineral is calcite, and this occurs sparingly.

PLACER MINES.

The Dixie Creek placer mines were discovered about 1862, and were reported rich, though no data as to production are at hand. Raymond's report for 1870 contains the statement that at that time there were 100 white men and 200 Chinamen employed, and that the fine, scaly gold was 860 fine. In 1873 the creek is reported as turned over to Chinese labor. In 1882 two small hydraulic plants were in operation, producing $30,000 (Mint report). At the present time very little placer mining is done.

The placers consist of the gravels accumulated in the present creek to a depth of 10 or 15 feet. The workings extend upstream from Prairie for 5 miles, or to the entrance of the diorite canyon, where the grade becomes very steep. The width of the gravel-covered river bottom is from 300 to 800 feet, the whole of which has been worked.

Six miles east of Prairie are the old Spanish Diggings, which have yielded a moderate amount of gold. The upper end of John Day Valley contains no placers. On the east side of Dixie Butte are the old placers of Happy Camp, still worked on a small scale by Chinese. Northwest of the same mountains are the Ruby Creek placers, still worked by whites and Chinese. Small placers are also reported from the head of Camp Creek.

CANYON DISTRICT.

GENERAL FEATURES.

The celebrated placer mines of Canyon are situated in the upper drainage basin of the South Fork of John Day River. The valley here widens to a broad depression, about 18 miles from east to west, and from 4 to 8 miles from north to south. In contrast to the narrow and heavily timbered valleys of the North and Middle forks,

A. JOHN DAY VALLEY.

B. CANYON.

this is a bare expanse of gravelly pasture land with strips of alluvial soils along the river from a quarter mile to 1 mile wide. The elevation at John Day is 3,000 feet; at Prairie, 3,500. The climate is fairly mild and dry, the water supply ample; in consequence the valley was settled soon after the discovery of the placers, and has for thirty-five years supported a prosperous community of cattlemen and farmers. North of the river the hills rise gradually and culminate in a timbered ridge forming the divide between the Middle and South forks of John Day River. The eastern end of the valley is surrounded by dark forested mountains rising to about 6,500 to 7,000 feet. At the very head of the valley there is, however, an unexpectedly low pass (elevation about 4,500 feet), through which a wagon road leads over to the Malheur River Basin. South of the valley the picturesque Strawberry Range rises abruptly, with serrated peaks, culminating in Strawberry Butte, with an elevation of about 8,600 feet. Toward Canyon the sharp ridges are a little lower, but still attain 8,000 feet. The range presents a steep but not very regular slope, with numerous salients and deeply incised canyons. Hot springs are found on Reynolds Creek in the uppermost part of the valley.

GEOLOGY.

The older pre-Miocene diabases, slates, and serpentines from the north side of the valley have been described under the heading "Quartzburg district" (p. 709). The eastern end of Strawberry Range, including the butte of the same name, is built up of Tertiary lavas. But at the foot of this mountain the underlying rocks appear, and their contact gradually rises westward, until in a short distance they form the summit of the mountains, culminating in a group of peaks and ridges which a few miles south of Canyon attain 8,000 feet above the sea. South of Prairie, below Strawberry Butte, serpentine appears in great development. It reaches 900 feet above the foothills, and also continues westward across Indian Creek. At Gillespie's sawmill it contains small bunches of chromite. The range was not ascended any farther than to the claim known as the Oregon Wonder, at an elevation of 6,300 feet; but the color and configuration of the high ridges back of Canyon indicate that they are composed of a granitic rock. Prospectors state that diorites and porphyries are the prevailing rocks, and in the gulches, coming down from the peaks, are abundant cobbles of a very coarse diorite with hornblende crystals up to 2 inches in length.

Above Canyon serpentine crops below the gravels almost within the limits of the settlement. Immediately above and on the west side fissile clay slate begins, with east-west strike and steep southerly dip. This continues for a few hundred feet, with a smaller mass of serpentine intercalated with slates. The relations between the two rocks are not clear, though the serpentine, an altered igneous rock, is probably intrusive in the slates. Above this follows another belt of serpentine about 1,000 feet wide and adjoined on the south, without well-exposed contact, by diabase and diabase-porphyry. At this point the canyon becomes deep and narrow; on the east rises the pronounced salient, Canyon Peak, which is also made up of diabasic rocks.

In general there is a marked similarity in geological structure between the Greenhorn Mountains, Dixie Butte, and the Strawberry Range. All of them are built up of diorites, diabases, and serpentines, inclosing smaller masses of sedimentary rocks, usually clay slate.

Extensive areas of basaltic and andesitic rocks surround John Day Valley. Most of them, it is believed, are of early Neocene age. The road from Austin to Prairie, after crossing the divide, descends over long ridges of pyroxene-andesite, both massive and brecciated. Lower down the gradually flattening ridges are made up of massive basalts, and these continue for 3 miles, down to the level of the valley. The same fine-grained, often vesicular basalts form the low hills bounding the alluvium on the north for several miles east of Prairie. Augite-andesite directly overlies the argillite on Dixie Creek a couple of miles above the junction with the main river, and it is, indeed, probable that the andesites are the older of the two rocks. All the way down to the town of John Day basalt bluffs follow the north side of the river, gradually increasing in height; near John Day they are about 500 feet high. In places white tuffs alternate with the basalt. The surface ascends gradually from the bluff to a moderately high divide, the slope probably indicating the surface of the lava flows. At a few places near John Day the black, glassy olivine-basalt appears on the south side of the river, but the exposures are usually small and covered by gravels.

Along Canyon Creek above John Day the basalt is overlain by a considerable thickness of light-colored rhyolitic tuff, extensively used as a building stone at Canyon.[1] Above this tuff again rest more recent gravels.

The uppermost part of the valley was not visited, but it is believed to be entirely covered by basalt and andesite, these extensive areas forming a continuation of the area surrounding Austin and extending over the headwaters of Burnt River. Without much doubt this area of lavas continues and forms the summit of the Strawberry Range to a point a short distance west of Strawberry Butte. The form and color of the jagged ridges indicate clearly enough their volcanic origin. Strawberry Butte is formed by a great number of superimposed dark lava flows, and was no doubt once the locus of a most intense eruptive activity. The rock forming its slope is a basalt cut by a rhyolite dike of immense size.

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[1] This rhyolite is evidently the same that Dr. J. C. Merriam describes under the heading Rattlesnake formation, which he considers of Pliocene age (Univ. Cal., Bull. Dept. Geology, Vol. II, No. 9.)

The broad extent of the valley from Prairie across to the foot of Strawberry Butte is a gently sloping surface covered with coarse basaltic gravel. Broad gulches cut in this slope reveal thick strata of these coarse gravels interstratified with some sandy material. At some point near the river coaly material has been found, no doubt embedded in these strata. West of Prairie the basalt north of the river is for some distance covered by these gravels.

Along the road down to John Day, volcanic bluffs, as stated, follow the north side of the river. The south side of the alluvium is bordered by lower bluffs, from 100 to 300 feet high, less abrupt and with smoother outlines. They consist of coarse gravel with occasional softer strata, and in several places are seen to rest on basalt (fig. 85). All these gravels form a part of the old, late Neocene flood plain which shortly after the close of the eruptions covered the John Day Valley to a height several hundred feet above the present river level. The position of this flood plain indicates that the river then took a course from 2 to 3 miles south of its present channel. The exposures at Canyon (see below under "Placer mines"), indicate that the bottom of these old river deposits lies considerably below the present bed of the river.

The most recent deposits are the alluvial sands and gravels along the present river course. These are over 1 mile wide at the junction of John Day River and Strawberry Creek. Two miles below Prairie are narrows, where a little canyon has been cut through a bed of basalt. Below this the alluvial deposits are from 1,000 to 2,000 feet wide.

GOLD-QUARTZ VEINS.

Canyon Peak, the bold salient from the main range which rises back of Canyon, consists of coarse gabbro or gabbro-diabase containing irregular masses of a dark-green, finer-grained diabase or diabase-porphyry. This hill is celebrated for its rich pocket veins, and most of the placer gold in the vicinity is probably derived from its veinlets. The production from these veins is very difficult to estimate. At any rate it has not been very considerable, and few of the prospects rise to the rank of a mine. On the summit of Canyon Peak, 1½ miles above the Great Northern, is the Idaho vein. There is said to be a strong vein of quartz, in the vicinity of which many small pockets have been found. Some distance below is the Mountain View. Here, also, is a well-defined strong vein, 3 feet wide, crossed by a network of stringers carrying products of coarse gold.

The Great Northern mine is located 2 miles southeast of Canyon, on a steep slope 1,540 feet above the town, at an elevation of 4,700 feet. A very fine view of John Day Valley is obtained from this point. This deposit was discovered in 1898 by Ike Guker. Placers have been worked in the gulch a couple of hundred feet below it. In 1898 $30,000 was extracted from one of the seams in a surface cut, and prospecting operations have since that time been carried on by a company having its headquarters in Salt Lake City. The developments aggregate 2,000 feet of drifts and crosscuts.

The country rock consists of gabbro and irregular bodies of diabase-porphyry. The latter, being often soft and traversed by calcite seams, is locally called lime, though it is without doubt an igneous rock.

A surface pit, about 50 feet by 50 and perhaps 20 feet deep, shows decomposed rock cut by seams usually dipping 30° to 40° east or west. The bonanza mentioned above was extracted from one of these seams. From a tunnel level 50 feet below extensive drifting has been done in an attempt to follow these seams. A vein of quartz 1 to 2 feet thick has been uncovered, striking north to south, and dipping 25° W. This is practically barren and is accompanied by an impregnation of pyrite and seams of calcite. Some of the seams in the tunnel above the vein carried wire gold, with a tendency to crystallization, inclosed in calcite.

About 300 feet east of this point another strong quartz vein, 2 feet thick, has been found. This strikes east-west, and dips 35° S. It carries massive white vein quartz, in places stained green by chromium.

At Prairie Diggings, 3 miles east of Canyon, placers containing rough quartz gold have long been worked. In the same vicinity is reported a large vein of base character and, to judge from specimens, inclosed in slate. In Raymond's report for 1870 it is stated that the body of quartz mixed with country rock is 400 feet wide, strikes northeast to southwest, and dips 60° SE. In 1872 a mill had been erected and $10,000 extracted, but soon after this the enterprise was abandoned, the quartz being, it is stated, of too low grade.

Aside from the occurrences described, the Strawberry Range apparently contains few mineral deposits. Near the head of Canyon Creek, 7 or 8 miles southeast of Canyon, claims have been located. The Chambers group is said to show a strong quartz vein 5 to 30 feet wide, containing a little chalcopyrite and limonite. The strike is said to be N. 60° E. In the Will Cleaver group, in the same vicinity, similar ore is found, claimed to average $8 in gold and 4 per cent in copper.

Almost due south of Prairie, high up on the side of Strawberry Butte, a great number of claims have been located, the principal one known as the Oregon Wonder. A trail leads up to this place from Gillespie's sawmill (elevation 4,200 feet) near the mouth of Indian Creek Canyon. The trail for the first few hundred feet leads over serpentine. Above this rock lie heavy flows of basalt, which at the claims (elevation 6,300 feet) is cut by a big rhyolite dike at least 300 feet wide, the outcrops of which form a bold and precipitous cliff. This dike continues for a long distance eastward and a continuous chain of claims is located on it. The rock is a yellowish-gray to brownish lithoidal rhyolite, showing very pronounced flow structure. It consists of sanidine crystals embedded in a microfelsitic groundmass. Little spots and seams of limonite abound in it, and it also carries traces of silver, and occasionally traces of gold.

PLACER MINES.

The placers of Canyon are justly celebrated as the most important and productive deposits of the kind in Oregon. They were discovered in 1862, and in less than a year many thousand miners were at work on the gravel bars of the creek and in the gulches of the surrounding hills. During the first few years the production was very great, but exact figures will probably never be known. Estimates are made varying from $3,000,000 to $5,000,000 a year. In 1865 the product was estimated at $22,000 a week (Raymond's report, 1870), or about $1,000,000 a year. In 1870 it had already fallen to $300,000 a year. In the following year the production was still further reduced, but remained for a long time about $100,000. The Mint reports for 1883 and 1884 estimate $87,000 and $80,000; for 1890 $72,000, and for 1891 $100,000. While the figures are incomplete and untrustworthy, it is scarcely probable that the total production much exceeds $15,000,000. In 1882 there were 16 hydraulic plants (many of them small) in operation, and two-thirds of the products were derived from Chinese companies.

At the present time both white and Chinese miners are operating, mostly on a small scale. Mines near Marysville and the Humboldt hydraulic mine were worked. The amount annually extracted from the placers during the last few years probably varies between $30,000 and $50,000.

The water supply is abundant, being secured from Canyon Creek and gulches east of it. The principal ditches are reported as follows:

Ditches in Canyon Creek district.

Name.	Miles.	Capacity (in miner's inches).
Miners	20	700
Hillis	11	800
Thompson	4	600
Humboldt	8	1,200
Lone Star	4	500
Forlorn Hope	4	500

The section exposed along Canyon Creek above John Day shows well the position of the older gravels and is illustrated in fig. 85. Resting on basalt and rhyolite tuff are heavy, coarse gravels, which are well exposed on the west side of the creek at Canyon, where they are 150 feet deep and overlain by finer gravel, in part sandy or clayey. At the Humboldt hydraulic mine 80 feet of the latter is exposed. On the south side of the creek, on the road leading up to Marysville and the Great Northern mine, much of these overlying sandy and clayey sediments are exposed, and they reach up to the foot of the mountains at an elevation of 3,900 feet, 750 feet above the town. In the gulches descending from the gold-seamed Canyon Peak, which have cut into these soft deposits, rich placers are found. Some of these gravels are worked now near Marysville.

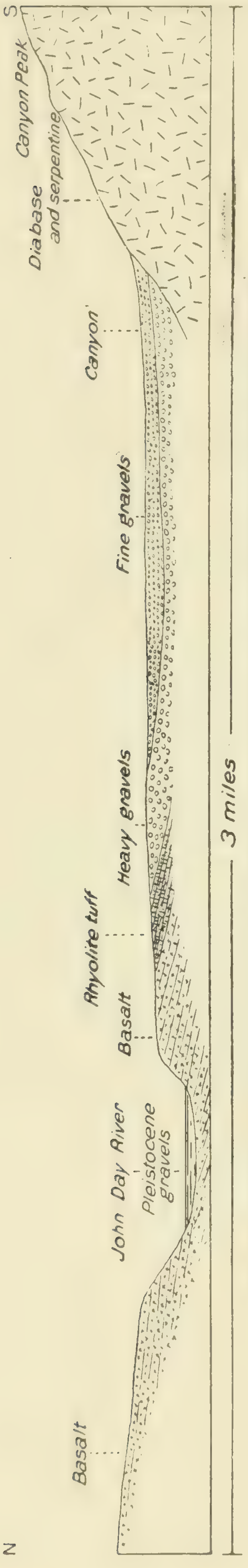
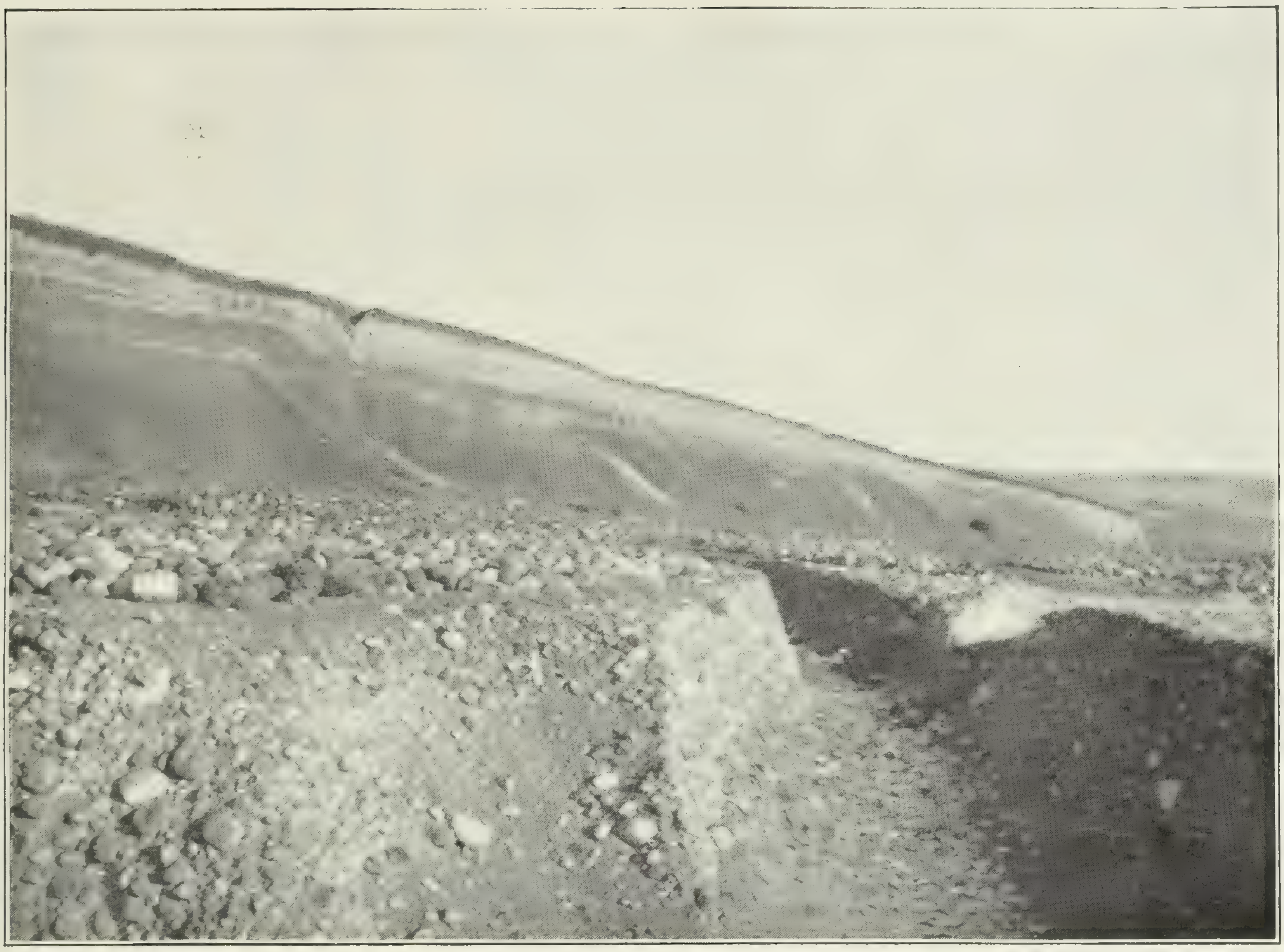


FIG. 85.—Section across John Day Valley at Canyon, showing Pliocene gravels resting on rhyolite and basalt.

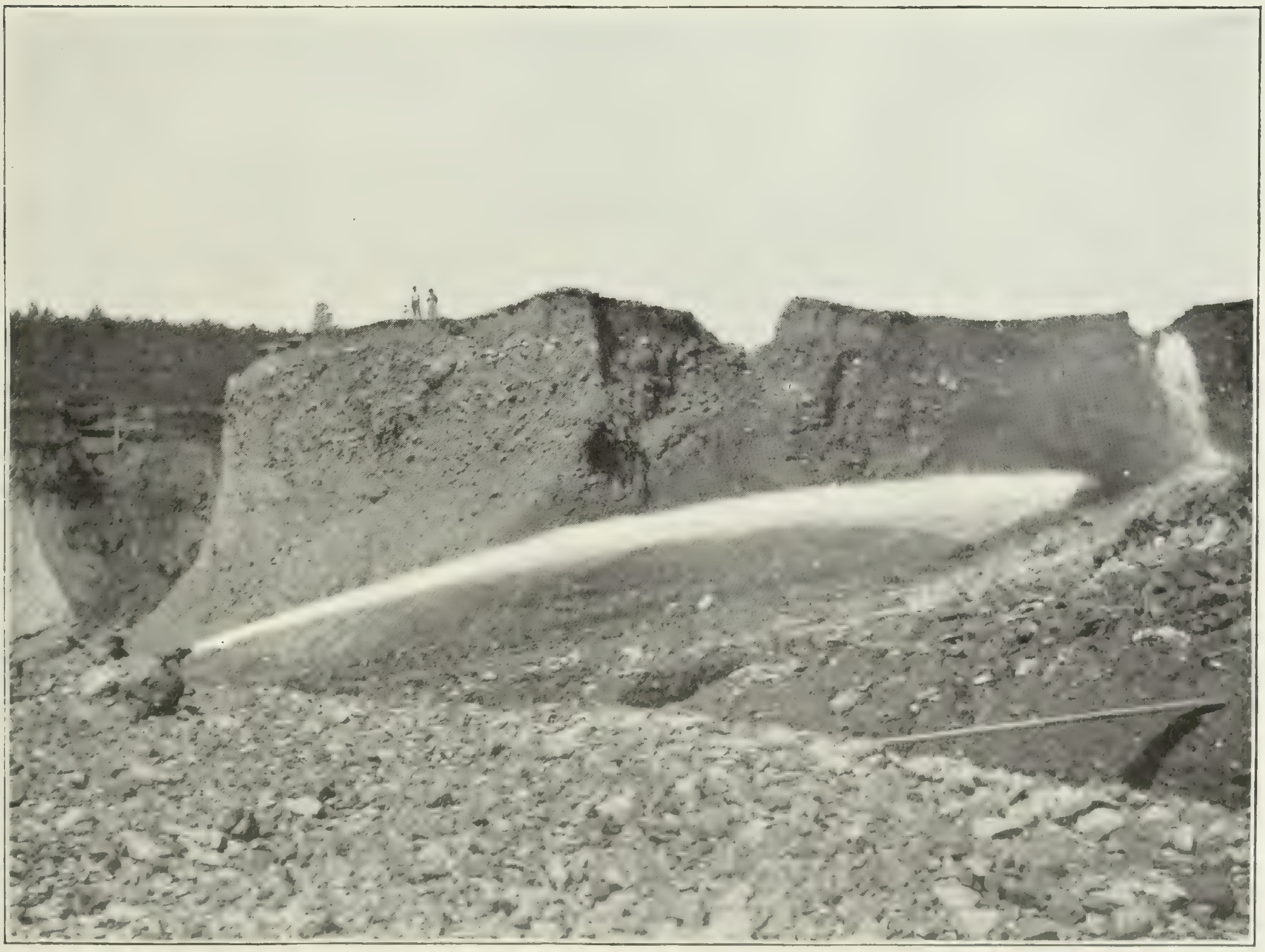
In the creek bed near Canyon a shaft is reported to have been sunk in 1873 to a depth of 300 feet without reaching bed rock.

It is clear that there is a great complication of deposits at Canyon, gravels of very different periods being present, and considerable time would be required to establish the exact relations. On the whole, it seems that shortly after the eruption of the basaltic and rhyolitic lavas flowing down from the north the stream was crowded over close to the mountains and heavy gravels accumulated in it. This must have taken place in the Pliocene epoch. The bottom of this channel has never been exposed. It is probable that the Pliocene gravels cover earlier accumulations of auriferous gravels, but that these can ever, if found, be profitably worked is extremely unlikely. The coarse gravels are very poor in gold—in fact, practically barren.

As the deposit deepened the width of the river bed increased, and several hundred feet of finer sediments were deposited on top of the coarse gravels. At the same time the detritus from the high mountains on the south began to push the river northward again, and during this gradual process the high bluffs on the north side of the river were formed.



A. HUMBOLDT PLACER MINE.



B. NELSON PLACER MINE.

The finer gravels are workable only at certain places. The most important locality is the Humboldt mine, 150 feet above Canyon and on the western side of Canyon Creek. Hydraulic operations have been carried on here for many years. A strip of ground half a mile long and several hundred feet wide has been washed, leaving a bank 80 feet in height (Pl. LXXIV, *A*). The bed rock is formed by coarse, cemented gravel; the pay is said to be concentrated in the first 4 feet overlying the bed rock. The exposed bed rock is nearly level, but is said to slope gently westward. This gravel mine has been worked for over thirty years, the output being reported as from $10,000 to $20,000 per season. These gravels, no doubt, represent the bed of Canyon Creek at a time when the main stream had already been pushed northward to nearly its present position. The rich gravels of Marysville, situated on the hill 1½ miles east of Canyon, and the gravels of the present gulches above Marysville are comparatively recent deposits; they are derived from the rich pocket vein of Canyon Peak, and some of the deposits have been worked almost up to the veins. Most of the gold has, however, been caught on the clays and gravels of the older river sediments, below the outcrops of the older rocks.

With the final establishment of the present drainage, Canyon Creek has been deepened to its present level. Its bed is from 200 to 600 feet wide, covered with gravels to a depth of 15 to 18 feet. These have, of course, been worked over, some parts more than once, but a certain amount of gold is still found concentrated on the bed rock. The workings extend for 5 miles up from John Day River. In 1900 prospecting shafts were sunk in these gravels with a view to dredging operations, and the results are said to have been satisfactory. The placer gold from Canyon is often 900 fine, and sometimes, as at the mouth of Canyon Gulch, 990, or $19.82 per ounce. The gold from the quartz veins averages 830 fine.

Above John Day there is apparently not much gold in the main river, but below this place for several miles the bars have been, and are still, worked by derricks and wheelbarrows. The depth to bed rock is usually only about 18 feet. Extensive prospecting for dredging ground was recently undertaken 4 miles below John Day by the Pomeroy Company, of Portland. The results have been so satisfactory that a dredger will soon be erected here. The gravels are reported to average over 30 cents per cubic yard, most of the gold, of course, being found on the bed rock. Bed rock of serpentine and slate shows at intervals, according to Mr. J. H. Pomeroy, in the river below John Day, and the gold is often so coarse that it must be of local origin instead of having been washed down from Canyon Creek.

At Spanish Gulch, about 70 miles west of Canyon, on Crooked River, auriferous gravels were deposited on serpentine, and have been worked for many years. A production of $1,400 is given for

1882 in the Mint reports. In 1898 $16,000 was taken out in a couple of months, the gold being very coarse. This locality, which was not visited, is, as far as known, the most westerly point of the gold belt of eastern Oregon.

Another district not visited is that of Fox, Hamilton, and Long creeks, about 20 miles due west of Susanville. Small but persistent amounts of from $1,000 to $7,000 of placer gold are yearly reported from this vicinity.

CHAPTER VI.

DETAILED DESCRIPTIONS OF MINING DISTRICTS (CONTINUED).

VIRTUE DISTRICT.

GENERAL FEATURES.

The Virtue mining district, one of the oldest in eastern Oregon, is situated about 7 miles east of Baker City, and extends for about 12 miles in a northwesterly direction, the width varying between 3 and 6 miles. It covers a region of low arid hills rising in the great bend of Powder River, and may be considered as the northwesterly continuation of the Lookout complex. The elevations range from 3,400 to 5,000 feet. The hills rise rather abruptly from Baker Valley and slope gently eastward toward the lower Powder River Valley. Most of the drainage is toward the latter. A rather remarkable feature within the hills is Virtue Flat, a desolate, sage-covered depression extending 8 miles east and west by 2 miles north and south. The water supply is very scant, the only flowing stream being Ruckles Creek, practically outside of the district.

GEOLOGY.

The predominating rock of the northern part of the district is a lighter or darker greenish-gray dioritic rock of granular texture, which nearly always bears evidence of strong crushing, but rarely of schistosity. Frequently the rock is a veritable breccia, the different fragments being cemented by seams of feldspar or zoisite. The feldspars are largely converted into a flinty white mass resembling saussurite, and the hornblende seems uralitic. The microscope shows, in fact, that the rock is rather a saussuritic uralite-gabbro than a true diorite. This rock decomposes to a very light-colored dusty soil. At Virtue mine the dark-green rock seems more like a tuff belonging to the surface eruptions of a basic magma, and, though the exposures are poor, it is believed to be interbedded with the argillites which appear a short distance south of Virtue mine.

The argillites occupy the whole southern part of the district. Their exposures are very poor, and a reliable strike and dip can scarcely be obtained. The rocks range from siliceous to calcareous, but are always dark in color. Limestone occurs 3 miles west-northwest of Pleasant Valley, and also about halfway between that place and Baker City. No fossils could be found, and the deposits are small lenses instead of definite strata. Still the appearance seems to indicate a general east-west strike of the formation, and the belief seems justified that they are continued westward by the argillites of the southern end of the Elkhorn Range.

A thin basalt flow covers the hills north of the Cliff mine and slopes gently eastward. The long slope toward the lower Powder River Valley is largely covered by shallow tuffs and gravels, apparently deposited in the waters of a Neocene lake. Many basaltic flows, also dipping northeast at angles of 10°, form the complex southeast of Baker City, rising to 5,077 feet. At their base is a thinner series of rhyolite and light-colored rhyolitic tuffs.

On the western side of the district, at the foot of Flagstaff Hill, extends the alluvium of Baker Valley. On the eastern side the Virtue Flat is covered by deep loams, sands, and semiangular gravel. On the hills surrounding it, up to 200 feet above the flat, lies fine, well-washed gravel. The very divide near Flagstaff is covered by deep, light-colored loam. In the gravels near the Virtue mine a molar of a mammoth has been found.

QUARTZ VEINS.

Quartz veins striking in many directions are found in the district, but the most prominent veins have a northwesterly course, a very unusual strike for this region. Individual veins are not traceable for long distances. The dips are usually southwesterly. Most of the deposits are normal, simple quartz veins, with very small amounts of sulphurets, and free, coarse gold of a high degree of purity. Pockety shoots of coarse gold are of frequent occurrence. The total production is probably $2,500,000.

Virtue mine.—As this mine is one of the earliest and largest producers of the whole region described, it may be desirable to outline its interesting history more fully. It is 7 miles nearly due east from Baker City in air line, and is situated in the foothills of the dry and barren ridges which partially fill the big bend of Powder River. The drainage around it is to the northeast into the lower part of the river; its elevation is 3,800 feet.

The discovery dates from 1862, and was due to the tracing up of rich placers filling the gulches below it. For ten years after its discovery it was known as the Rucker or Union mine. A great deal of work was done in early days, as shown by Raymond's report of 1870. From 1871 to 1878 it was worked nearly continuously, largely by Brown and Virtue. In 1878 it was sold to Grayson & Co., of San Francisco, and up to 1884 was worked in a more or less satisfactory manner. From 1884 to 1893 the mine was idle, but in the latter year work was resumed and continued with excellent results until 1898, when, after a short period of idleness, it was sold to the Consolidated Virtue Mine Company, of Montreal, Canada, also owners of the adjoining Collateral mine. After a short period of work in the upper parts of the mine, it was again closed on August 1, 1899. When visited, the mine was, unfortunately, shut down. The property is equipped with a 20-stamp mill.

The production up to 1878 was $1,250,000. From 1878 to 1884 $200,000 is the estimated amount. From 1893 to 1898 the production was $739,000, the maximum being reached in 1896 with $259,000 and the minimum in 1898 with $13,100. The total production is thus $2,189,000.

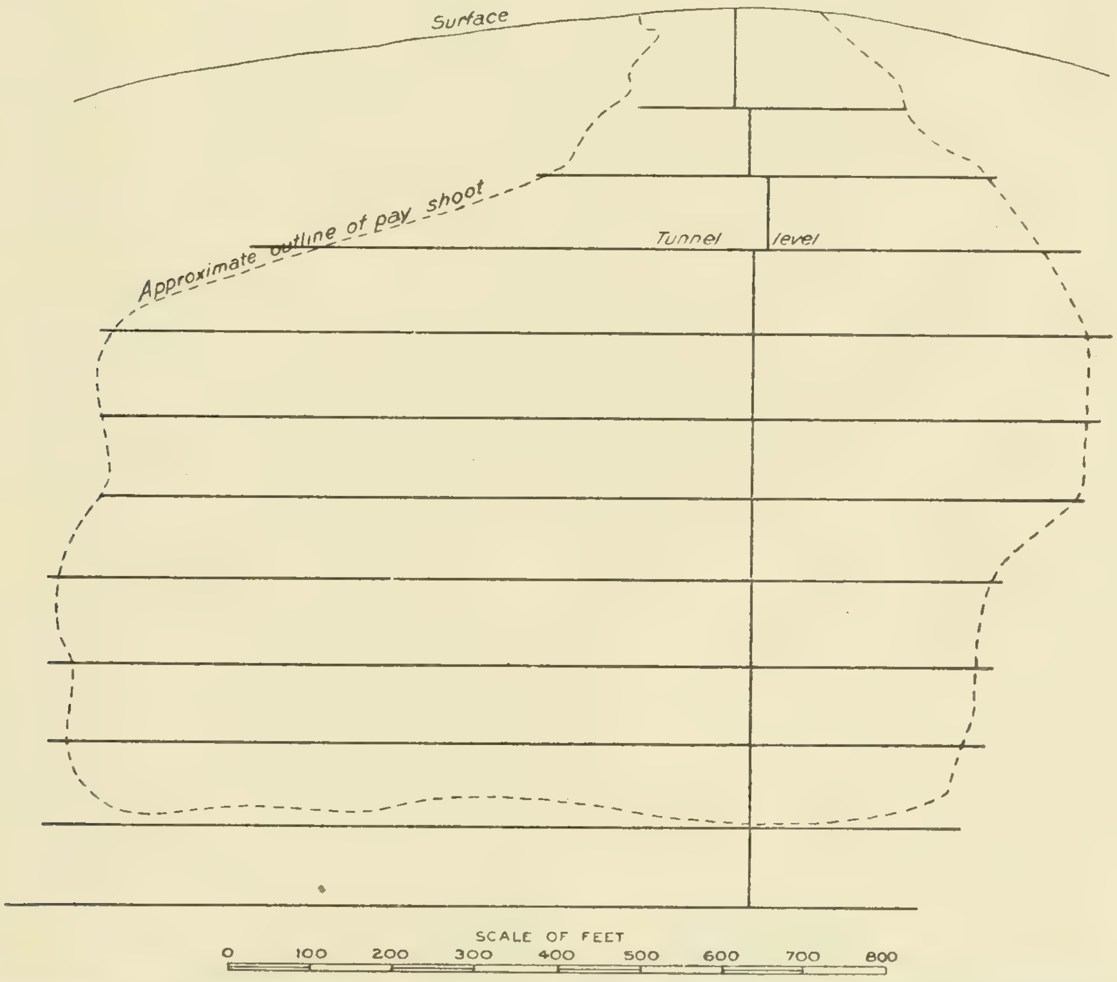


FIG. 86.—Approximate workings and extent of pay shoot in Virtue mine, in projection on the plane of the vein.

The earlier developments consisted of three tunnel levels, the lowest of which is 300 feet below the croppings. From the lowest tunnel a vertical shaft was sunk 800 feet deep, and at each 100 feet crosscuts were made to the vein. The levels extend from 200 to 400 feet north and 800 to 900 feet south from the shaft.

The country rock is a greenstone of very fine grain and dull greenish-gray color, some of it having a serpentinoid appearance. It is an old volcanic tuff or breccia, probably of the same age as the slates of the White Swan or the gabbro and diorites of Flagstaff. Much of it is so altered that its original character can be recognized only with difficulty. It has no slaty structure.

The vein strikes northwest and dips 45° to 80° SW., its width varying from 6 inches to 12 feet, being on an average 14 inches. Southeasterly it may be traced into the adjoining Virginia mine.

The ore is a white, normal, coarse vein quartz with some drusy cavities. It contains free gold, which often is very coarse and shows imperfect crystallization; it is unusually pure, reaching a fineness of 940. The quartz contains an extremely small amount of sulphurets, consisting of a little pyrite and chalcopyrite. Occasionally the quartz is banded by shearing, and this is considered the best rock. The country rock near the veins contains seams of calcite and pyrite, but ordinarily carries no value. The richest ore occurred near the surface. In 1870 the average yield was $20 per ton; in 1873, $40 per ton was reported; in 1875, $24 per ton. From 1893 to 1898 the ore averaged $15 or $16 per ton. Still richer chimneys were occasionally found in the main ore shoot.

The approximate extent of the pay shoot is shown in the accompanying figure, the data having been kindly furnished by Mr. R. R. Grayson. From the seventh level up, the ore was stoped for the full distance of the drifts, the ore shoot being practically 1,200 feet long. According to the earlier data in Raymond's report of 1870, the upper part of the shoot above the lowest tunnel level was much shorter. Mr. Grayson states that "no stoping was done between the eighth and the seventh level, as the ledge matter was broken up and carried but slight values." The mine was then abandoned, and since that time it has never been unwatered.

An interesting feature is that the water in the shaft is very abundant and stands a short distance below the collar, that is, a couple of hundred feet above the level of the valley. Moreover, it is warm or tepid, so that it must represent an ascending column of the underground circulation. The high temperature was a serious obstacle to the working of the mine.

As may be expected, there are a great number of claims and prospects near the Virtue mine, but none of these have as yet proved important producers. The southeasterly extension of the Virtue has been worked by means of a shaft in the Virginia. Adjoining on the southwest is the Collateral, a vein said to be similar in character to the Virtue, and accessible by crosscuts from the lower levels of the Virtue workings.

Flagstaff mine.—This is situated 6 miles northeast of Baker City, on a small knob in the low range of hills separating the upper and lower Powder River valleys. The elevation is 3,900 feet. During the last few years the mine has been developed with a 730-foot incline and drifts aggregating 5,500 feet. A 10-stamp mill was erected in 1898 and run for a few months, yielding a production of $32,000. The mine has been idle since that time.

The country rock is a diorite or gabbro, showing evidence of much irregular crushing. The vein strikes east-northeast, and dips 55°; it is very persistent, 5 to 8 feet wide, with 18-inch-wide pay streak.

The ore is a white, massive quartz, with some calcite and occasionally scheelite, but containing scarcely any sulphurets, except a little stibnite and tetrahedrite. The average value per ton is said to be $16. The fineness of the bullion is 820. Plate amalgamation does not extract the full value, and tailings should be further treated, perhaps with the cyanide process. Three levels are turned 100 feet apart, except the first, which is 160 feet below the surface, and a considerable amount of ore is said to be blocked out. The fourth level is not opened. In a crosscut from the third level a new vein was struck, said to show 2 feet of quartz of excellent value. Water was not found in the shaft until 575 feet below the surface, or 450 feet vertical depth, that is, about 100 feet above the level of Powder River at Baker City.

Other mines and claims.—Half a mile north of the Flagstaff is the Cliff mine, the vein of which crops just below the basaltic cap in crushed and partly schistose diorite. It is developed by a vertical shaft 300 feet deep. The vein has a northerly strike and consists of 1 to 3 feet of soft quartz in decomposed dioritic rock. Scheelite in considerable masses was identified from this mine by Mr. C. L. King, of Baker City. A little calcite also occurs in the quartz.

In the foothills north of Virtue Flat, 3 miles east of Flagstaff, the Columbia-Friday vein crops through several locations. On the Friday and the Columbia the vein has been opened by small incline shafts. The vein is similar to the Flagstaff, strikes northwesterly, and dips 40° SW. The quartz of the Columbia shows very fine comb structure.

Many prospects are found on the ridge 500 feet high 1 mile south of the Flagstaff, the principal developments being on the Rachel claim. The country rock is a crushed and partly schistose diorite. In general appearance the vein is like that of the Flagstaff; the strike is northwesterly. In some of the prospects stibnite has been found.

The White Swan mine is situated 3 miles east-southeast of the Virtue at similar elevation and in the same desolate foothills. Here, also, rich gulch diggings led up to the vein. The mine was worked most successfully about ten years ago, and has been idle since 1897. The production is estimated at not less than $200,000. The Mint reports give $72,000 and $72,642 as the output during 1891 and 1892. The developments consist of a nearly vertical shaft 300 feet deep, with drifts on the various levels. The mill equipment consists of 10 stamps. In contrast to that at the Virtue a black, soft argillite, with a few sharply defined dioritic dikes here forms the country rock. The vein strikes northwesterly and is nearly vertical. The quartz is white and massive, like that of the Virtue, and contains a very small amount of sulphides. A little calcite is present. Several other veins, not developed, are found in the immediate vicinity.

The argillite hills south of the Virtue and southwest of the White Swan contain many small veins, in some of which good chimneys of ore with coarse gold have been found. Among them are the Mabel, St. John, and the Carrol B. In the last named a rich streak has recently been developed. The Mabel produced $7,000 from a similar pocket.

Brazos mine.—Two miles north of Pleasant Valley and the same distance south of the White Swan is a vein covered by the Pleasant Valley and Brazos claims. On the latter the elevation is 4,100 feet, the drainage being southward toward Burnt River. The development of the Brazos is of recent date, and a 10-stamp mill was erected on it late in 1900. The developments consist of a tunnel with 1,000 feet of drifts, no ore having been stoped at the time of the visit, in August, 1900.

A black argillite, most of it soft and crushed, and without clearly defined bedding planes, forms the country rock. The vein strikes northwesterly and dips 20° to 30° SW. The croppings, which are not conspicuous, rise to 125 feet above tunnel level. The hanging wall is clearly defined by a clay seam, while the foot wall is also well marked. The width averages 3 or 4 feet, the vein matter consisting of soft, black argillite full of little nodules of quartz, rarely forming continuous veins. The appearance suggests that movements on the vein have separated the quartz into isolated lenses. All of these quartz seams and nodules carry gold, some of it being coarse. The pay shoot is claimed to extend for 400 feet along the vein. The ore is probably low grade, but the cost of extraction and treatment, on the other hand, should be very low.

In its northwesterly continuation the Brazos vein changes character, and the claim is exposed on the Pleasant Valley by a 175-foot incline as a normal quartz vein filled with 3 to 4 feet of massive quartz said to assay from $2 to $7 per ton.

One mile east of Pleasant Valley two normal quartz veins crop on the Keystone claim with a northeasterly strike and flat southeasterly dip. The developments consist of a small shaft and several tunnels and cuts.

PLACER MINES.

The only placer mines in the district were found in the gravel-filled gulches leading up to the Virtue and White Swan mines. These are now exhausted and only occasionally worked on a small scale.

VICINITY OF NORTH POWDER.

GENERAL FEATURES.

North Powder is a little town situated at the northern end of Baker Valley, at an elevation of 3,250 feet, near the point where Powder River abruptly turns from a northerly to a southeasterly direction. The North Fork, heading among the granite peaks of the northern

Elkhorn Range, joins the main stream in this vicinity, and a short distance below this junction the latter enters an abrupt though not very deep canyon, through which it flows for about 16 miles before entering the lower Powder River Valley, the average elevation of which is 2,700 feet. This narrow and steep canyon bears every evidence of recent excavation. At the bend it is cut in older rocks, while farther south it is incised in the covering lavas. A low, lava-covered divide with maximum elevation of 3,440 feet here separates the Powder River from the Grande Ronde Valley. The narrow point in the bend is occupied by bare, arid hills, rising 600 feet above the canyon. Eastward and westward from the bend the hills are covered with basalt flows. The floor of the valley gradually rises west of North Powder and almost imperceptibly passes into the heavily forested hills between Wolf Creek and the North Fork. South of that river the contrast between the valley level and the foothills of the Elkhorn Range become much more marked. In the middle of the valley, south of North Powder, rise two isolated groups of hills, the southerly points, 500 feet high, being known as the Coyote Hills.

GEOLOGY.

The older rocks of this region are similar to the Triassic lavas from the foothills of the Eagle Creek Range, and probably belong to the same age. There is a marked absence of sedimentary formations, and most of the rocks might be classified under the general term greenstones. Along the principal mineral zone in the bend of the river, a locality known as the Farley Hills, dull, dark-green, fine-grained rocks prevail, containing much epidote and chlorite. In places they are cherty and partly silicified. A somewhat fresher, dark-gray rock from the Guthrie shaft proved to be an old basalt or metabasalt greatly altered and uralitized. At the bend of the river the canyon is cut in a medium-grained, somewhat crushed dioritic rock, which contains much orthoclase and is probably a monzonite.

The Coyote Hills consist principally of normal, dark diorite with numerous dikes. Some of these are lamprophyric, practically dark-green and very fine-grained diorite; others are pegmatitic, consisting of orthoclase, microcline, with a little quartz and augite. The foothills north of the North Fork are made up of dark-green, medium-grained uralite-gabbro and diabase. South of the river similar rocks prevail, but the débris indicates that argillite and slate are also present. Near the mouth of Muddy Creek Canyon the light-gray granodiorite of the Elkhorn Range reaches the foothills.

Tertiary volcanic rocks chiefly appear on the divide north of Wolf Creek and the sharp bend of Powder River. The prevailing rock is a black, glassy basalt, very similar to that occurring northwest of Medical Springs, and probably belonging to the same system of flows. At a place in the foothills near North Powder a gray rhyolite tuff also appears and is locally used as a building stone.

The basalt flows which begin north of Flagstaff mine in the hills between the upper and lower river extend westward into the district as far as Magpie Peak. The Pleistocene deposits are abundantly represented by the flood plain of Baker Valley, extending from Baker City on the south to the beginning of the canyon near North Powder on the north. The main river has not cut into the accumulated gravel of its alluvial deposits, but along the North Fork evidences of a somewhat more active erosion are seen. Westward from North Powder slightly undulating plains extend for several miles and then grade into gravel slopes, through which the river has cut a trench 20 to 40 feet deep, filled with the most recent deposits.

MINERAL DEPOSITS.

No mines of any importance have yet been developed in this vicinity, but there are many prospects and indications of mineralization. Fissure veins are seen in a few places only. The predominating type seems to be a pyritic impregnation in the old greenstones.

A belt of prospects extends for several miles along the base of the hills southeast of North Powder, the locality being generally known as the Farley Hills. Seven miles east of Haines is the Jenkins group of prospects, which were not visited. Two miles northwest of the latter place is another group of claims, the most important of which is known as French Joe. The greenstone is here covered by a few feet of iron capping, chiefly limonite, which is said to contain some gold. Associated with it is much partly silicified and iron-stained rock. A prospect hole close by shows magnetite and epidote, and another, not far distant, some copper-stained and silicified greenstone. No vein quartz is visible. About 3 miles farther northwest, in the same low foothills, are the claims owned by Forsey and Coppinole. Here much iron-cap and honeycombed quartzose material is exposed in a shaft 40 feet deep. This ore is reported to contain over $6 in gold. Samples from this and the previously described claims showed only small quantities of gold and silver, but it is stated, on apparently reliable authority, that some very rich ore has been found. A mile farther northwesterly is a group of claims covering croppings, 200 feet wide, of rusty and cellular iron cap. The Buckeye and Pittsburg claims extend to the west and east from this place, while another line of claims, the Keystone, Gallagher, Climax, and Delta, is laid out from north to south across the same croppings. A 50-foot shaft with drifts represents the development on the Keystone, and shafts of about the same depth have been sunk on the Delta, Gallagher, Buckeye, and Pittsburg. The Buckeye, also known as the Guthrie, is said to show a considerable body of auriferous material. East of these claims are others which are reported to carry oxidized copper ores. It seems most probable that all these deposits were originally impregnations of pyrite and chalcopyrite along certain lines and, in the main, similar to those found in the foothills of the Eagle Creek Range. Extensive decomposition and oxidation, due to the low ground-water level, has converted these impregnations into masses of iron capping. The copper and the silver have been extracted and the small amount of gold concentrated. At least this seems the most plausible explanation.

Five miles west of North Powder, in the low foothills half a mile north of the North Fork, are several prospects showing narrow quartz veins with reported good values in gold. They are contained in greenstone and have a northerly strike and an easterly dip.

Six miles west of North Powder, in the same locality and in the same country rock, are several copper prospects, the principal one named Copper King. The deposit is developed by an inclined shaft 150 feet deep. The ore shows some chalcopyrite, as well as malachite and chrysocolla. At the southern foot of the most prominent peak in the Coyote Hills a well-defined quartz vein is exposed by a small shaft and several hundred feet of tunnels. The yellowish, honeycombed quartz carries some stibnite, and gold values of about $7 per ton were obtained from it. The vein strikes north and south, and dips 70° W.; width of vein matter is 2 to 3 feet; width of quartz, 2 to 6 inches. The vein crops in diorite. Close by is a prospect showing dark diorite, copper stained on the joints.

PLACER MINES.

Among the few placers known from this vicinity are those of Bulger Flat, situated between the Elkhorn Range and the sharp conical hill rising at its foot 7 miles west-southwest of North Powder. The production is small, but has been pretty constantly maintained for many years. Placers have also been worked near the head of Wolf Creek, 10 miles northwest of North Powder. The North Powder and its tributary, Antone Creek, do not seem to contain any placers, nor are any other kinds of deposits reported from their watershed.

COPPER BUTTE DISTRICT.

GENERAL FEATURES.

This mining district, which has attracted much attention recently on account of its copper deposits, is situated about 18 miles northwest of Baker City, in the first foothills of Eagle Creek Range, rising from the alluvium of lower Powder River Valley. The low arid hills ascend very gradually toward the higher basaltic plateau, which is covered with forest, and the elevations in the copper-bearing district vary from 2,700 to 4,000 feet. The drainage is toward Powder River, by a series of creeks and gulches which do not cut far back into the mountains. The water supply is not abundant.

GEOLOGY.

The foothills below the basalt cap are occupied by a series of old eruptive rocks associated with minor masses of clay slates and limestones. The outcrops are generally poor and the whole surface is deeply decomposed, often rendering an exact determination of the rocks difficult. The old eruptives may be designated greenstones—that is, greatly altered basalts and diabasic basalts (metabasalts)—together with tuffs, which also have undergone much alteration. Some of the rocks were very vesicular, the cavities now being filled by calcite and zeolites. These old amygdaloid basalts were formerly often called melaphyres. The alteration consists in the abundant formation of chlorite, hornblende, and epidote. Alternating with these rocks are minor masses of black clay slate and lenses of limestone. One of the largest of these limestone lenses crops 1 mile northwest of Table Mountain and is called the Big Lime dike. It is at least 600 feet long and 100 feet wide. Smaller masses are found 1 and 2 miles north of Medical Springs; others at the mine of the North American Copper Company and near Gilkeson's ranch. Many of them appear entirely embedded in greenstone. The limestone is not greatly altered, but it was not possible to obtain any recognizable fossils, though there are many indeterminable remains of organic life. The stratification of this series is not well defined, but it is believed that it has a moderate dip and a northwesterly strike. From the great similarity to the rocks of Eagle Creek, adjoining this district on the east, in which fossils have been found, the age of this series is believed to be Triassic. The greenstones and tuffs should be considered as surface eruptions which took place along the shore of a shallow sea.

This area of old lavas is almost entirely inclosed by subaerial lava flows of a much later—Neocene—age. From Baker City to Medical Springs the gentle slopes down to the lower Powder River Valley are covered with shallow basalt flows in which the river canyon above the valley is cut. These flows extend continuously across the river, forming the high complex of hills north of Medical Springs, and, in fact, the whole region of the higher forested foothills. The flow structure of this lava is very well defined. Seen from a distance it forms a sloping table-land sharply rising above the bare foothills occupied by the older lavas; behind this table-land rise the high peaks of the Eagle Creek Range. The flows range in thickness from 200 or 300 to nearly 1,000 feet; their lower edge is marked by a prominent line of rocky bluffs. Two miles east of Gilkeson's ranch a point of this bluff, evidently underlain by clays and similar material, has slid down toward

Balm Creek, and forms an exceedingly confused topography, characteristic of landslides. The basalts are, as a rule, fine grained or glassy and vesicular.

MINERAL DEPOSITS.

The minerals of value occurring in this district are all found in the older Triassic lavas and slates. The Neocene basalts contain no deposits. The principal interest is claimed by the copper deposits, which have received much attention during the last two years; large areas are covered by claims of more or less value. The copper ores contain some gold and silver, but gold-quartz veins and placers are not found until the drainage areas of Goose Gulch and Eagle Creek are reached. These are described under another heading.

The copper deposits have been known for a long time. In Raymond's report for 1873 is a statement that "W. B. Crane & Co. sold their copper mine [at Copper Butte] to Messrs. Carson, Williams & Co., of Detroit, Mich." A furnace was erected and one smelting made of 4½ tons of copper. Since that time the copper deposits have attracted but little attention until the recent high price for that metal encouraged further prospecting. That copper is extremely widely distributed in these rocks admits of no doubt. Slight green stains and minute grains of chalcopyrite or chalcocite are very commonly found. As far as can be judged from the small developments, the majority of these copper deposits are not normal fissure veins, but replacements by chalcocite or bornite along certain ill-defined lines. Epidote and hornblende accompany the sulphides. A secondary development of native copper or oxidized copper minerals is often found near the surface.

Below the basaltic bluff half a mile east of the Medical Springs, at an elevation of 3,850 feet, is a copper prospect developed by a 70-foot shaft. The surface exposures are partly covered and unsatisfactory, but the dump shows some chalcopyrite in gangue of garnet, epidote, specularite, and calcite. Normal diorite and crystalline limestone are also present, but the diorite is probably a dike, for it does not show prominently on the surface. Though there does not seem to be much copper in sight, the deposit is interesting on account of its identity in mineral composition with the occurrences from the Seven Devils, Idaho. It is, in all probability, a contact deposit due to the metamorphic action of the diorite on the limestone in which it is intrusive. No other deposits of a similar type have thus far been found in eastern Oregon.

The claims of the North American Copper Company are located 1 mile southeast of Table Mountain, at an elevation of 3,300 feet and a short distance below the basalt bluffs. The country rock is here an amygdaloid metabasalt, with small veinlets of natrolite or similar zeolites. Prehnite was not observed. Much of the rock contains chalcocite, in fine distribution, associated with epidote. Near the surface the rock also contained finely divided native copper throughout its mass, and especially in the little white zeolitic seams. For more detailed description see page 630. Of well-defined fissures or veins there is no indication. A shaft 120 feet deep has been sunk in this copper-bearing rock and crosscuts extend for 80 feet. It is claimed that a large mass of this rock contains enough copper to be profitably mined, milled, and smelted. The assertion is based on the well-known record of the Atlantic mine in the Lake Superior district, in which ore containing 0.648 per cent copper, or 13 pounds per ton, has been treated at a profit, the total cost being $1.19 per ton. This certainly sounds promising, but it must be borne in mind that, even if a large body of copper-bearing rock exists here, it would not be possible to mine it as cheaply in eastern Oregon as in the Lake Superior region, that transportation would be higher, and that, owing to the presence of chalcocite, conditions for concentration and smelting are much more unfavorable. The Lake Superior estimates must be revised to hold good for eastern Oregon. Large quantities of 3 or 4 per cent ore might be handled profitably in the present case. The total expense could scarcely be reduced below $5 or $6 per ton.

Copper Butte is one of the earliest-known copper-bearing localities. It is situated on Clover Creek, near Gilkeson's ranch, at an elevation of 3,600 feet, and at the foot of the basalt bluff which overlooks the lower foothills. The road from Erwins, on the Powder River, at first ascends over low hills covered by tuffs and fine gravels, then crosses a belt of granite-porphyry about 1 mile wide, which probably is connected with the Sparta granite area, and then enters the greenstones and clay slates.

On the hill south of Gilkeson's ranch is a copper claim known as Little Baby. Two small shafts, in soft, black, clay slate, disclose what apparently is a vein striking northeast and dipping flat northwest. The vein is 1 to 2 feet wide and carries a very decomposed oxidized copper ore, chiefly malachite and chrysocolla, together with minute foils of a brilliantly yellow mineral which is a vanadate of copper containing sodium. It is closely allied to calciovolborthite and probably represents a new species. Half a mile north of the ranch is Copper Butte, with Copper Queen as the principal claim. Below the basalt bluff a considerable amount of oxidized ore, malachite, chrysocolla, and cuprite, was found, irregularly permeating the amygdaloid greenstone and greenstone tuff which form the country rock. Some of this was rich, and the remains of a small furnace and widely scattered slag rich in copper bear evidence to former attempts to work the property. About 100 tons of 12 per cent copper ore are said to have been shipped, and about the same amount of 7 per cent ore could probably be sorted out. The surface cuts are extensive and irregular and there are besides several short tunnels and shafts. Below the rich surface ore but little of value has thus far been found. Narrow seams are coated with malachite. Two of these seams are more regular than the others, strike northwesterly, and dip steeply; these contain, besides malachite, a little sulphide ore as bornite. No gangue is noticeable.

A few hundred feet northeast of these croppings a tunnel 400 feet long has been driven into the hill to cut a supposed ledge carrying some copper stain, but nothing has thus far been found.

A number of prospects have recently been located on Baker Creek 2 miles east of Gilkeson's ranch and a short distance below the basalt bluff. The country rock is the same altered greenstone. Many and extensive croppings of rusty and cellular iron capping are seen, and, in one place, copper stains. Although this iron cap is suggestive of pyritic deposits, the various cuts and tunnels seem to have developed very little of value. A few hundred feet below these croppings a body of impregnated rock, perhaps 10 to 20 feet wide, crosses the creek, and short tunnels have been driven on both sides. The rock is here fairly fresh and contains scattered pyrite and chalcopyrite, the latter made conspicuous by sulphate of copper incrusting the walls of the tunnel. A quarter of a mile farther down the creek a different and peculiar formation is found, consisting of strong outcrops of whitish silicified rock with much iron stain. No pyrite is visible. This rock forms a bluff 150 feet high, 200 feet wide, and extending for 300 feet on each side of the creek. This whole mass is said to be auriferous and to contain from a trace to $5 per ton in gold. It is probably an altered and silicified greenstone.

Many of the copper prospects are found on Goose Creek, some of them containing chalcopyrite. At the Snowstorm gold-quartz mine and also in the Goose Creek drainage are several copper claims. The surface shows much copper-stained float, and several 10-foot pits have disclosed the presence of vertical streaks impregnated with bornite in the dark-green chloritic diabase, often amygdaloid, which forms the country rock. In one pit three of these impregnated streaks were noted in a width of 10 feet. Spreading from the small masses of bornite are malachite and chrysocolla. There is no distinct fissure vein, nor is the bornite connected with any visible gangue. An average sample across 6 feet gave 2.44 per cent copper and, further, 2.3 ounces silver and 0.1 ounce gold per ton.

SPARTA AND EAGLE CREEK MINING DISTRICTS.

GENERAL FEATURES.

Eagle Creek is one of the principal tributaries of Powder River, and its several branches head far back among the alpine peaks of the imposing mountain range named after it. From their sources in the bare, rocky amphitheaters, formerly filled with glaciers, the streams flow through forested canyons opening here and there to beautiful, park-like valleys with luxuriant pastures. At the junction of the forks the canyon is about 1,000 feet deep, and even in the driest season carries an abundance of water. With gradually diminishing depth the canyon continues through the timbered ridges of the Eagle Range foothills and through the bleak lava flows skirting its base, until finally its stream emerges into the broad, alluvial Eagle Valley, where it joins Powder River.

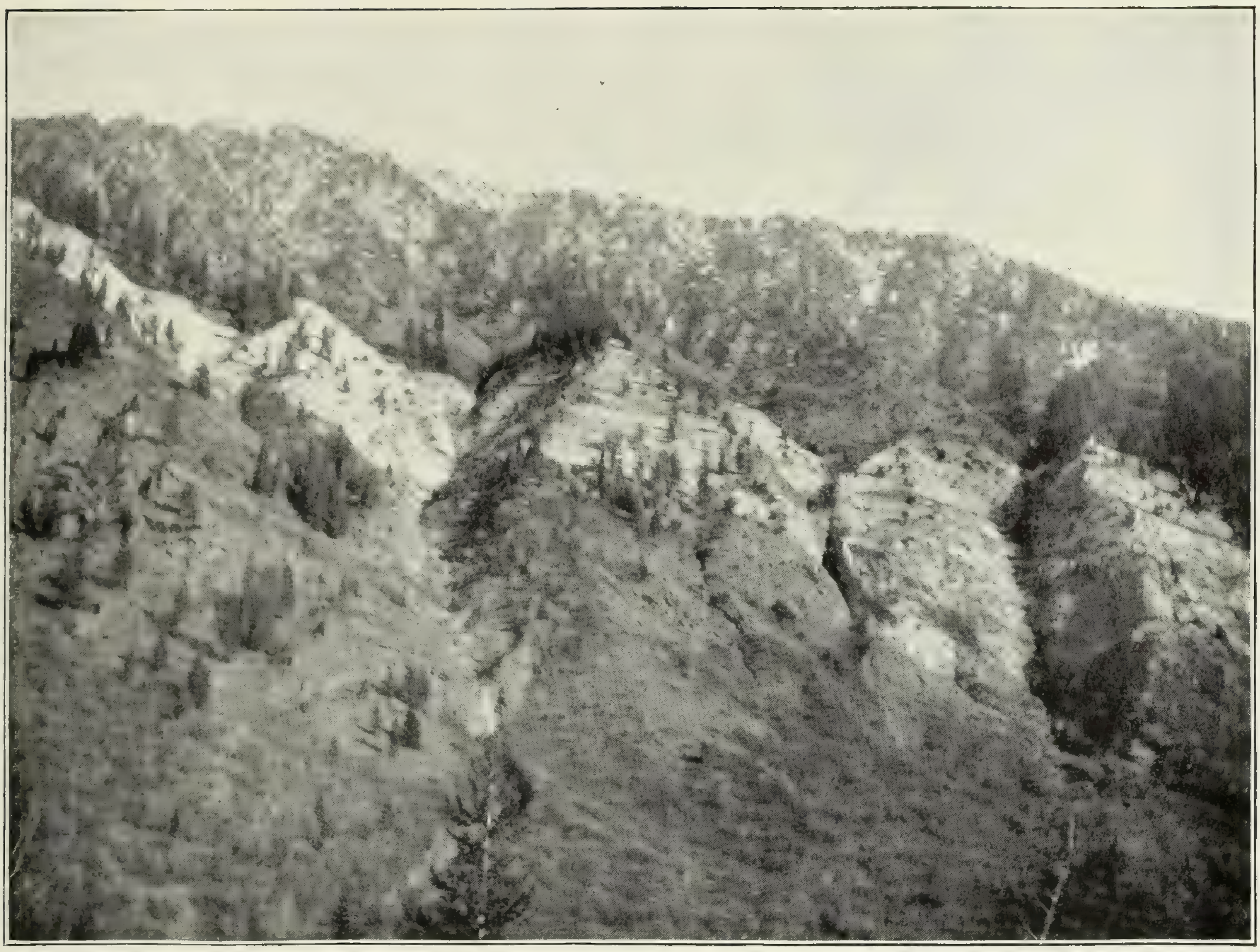
GEOLOGY.

Three main geological features may be distinguished. First, the granite area of Sparta; second, the great area of Triassic sediments forming much of the foothills and most of the high mountain region; and third, the basaltic plateau of Neocene lavas, the flows of which surround the Eagle Creek Range and fill the basin of the lower Powder River Valley.

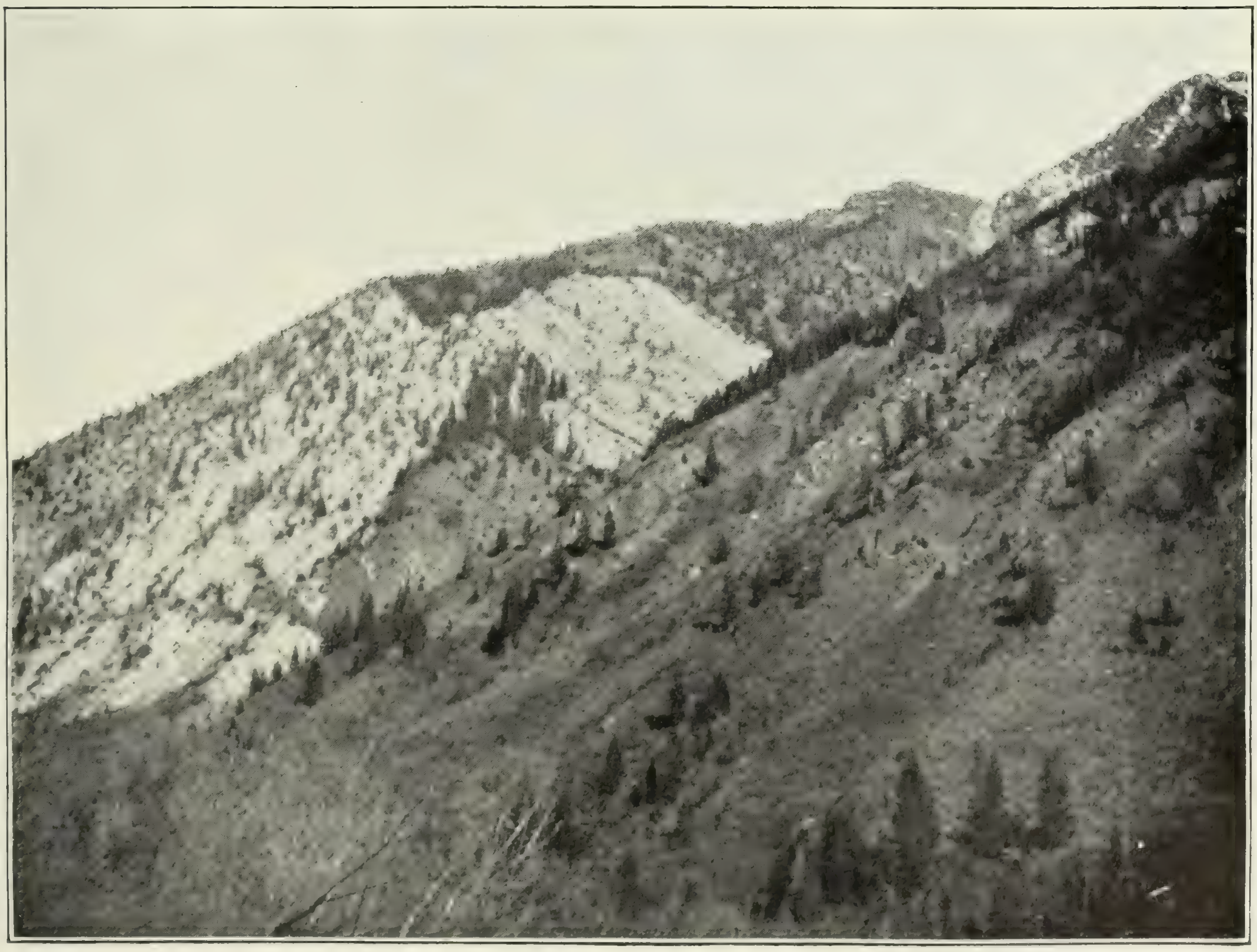
The Sparta granite occupies about 300 square miles at the end of the long ridge between Goose Creek and Powder River on one hand and Eagle Creek on the other. On the south and east it is covered by basalt; on the west it appears to change into the granite-porphyry exposed north of Keating. On the north it is replaced by the sedimentary series a short distance north of Sparta. The rock is a grayish, medium-grained, apparently normal granite, decomposed on the surface to a yellowish-gray, sandy soil, so that outcrops are rarely, if ever, seen, and fresh specimens can be obtained only in the mines 50 feet below the surface. The analysis shows it to be a soda-granite containing much albite. The relations of the granite to the Triassic sediments were not observed.

The Triassic series is well exposed on Eagle Creek. Rocks of the same age have been described from the Copper Butte district, but while there the prevailing rocks were old surface lavas (greenstones), here the sedimentary part of the series is developed much better.

Limestone and black slate in small croppings were noted a short distance north of the Dolly Varden mine on the road from Sparta to Lily White. Similar rocks were noted 2 miles west of Sanger, at the Sanger mine, and at Lily White. On the road from the latter place to Cornucopia gray, soft, calcareous shale and limestone, with northerly strike, crop near the crossing of Eagle Creek, and the bluff at the bridge shows nearly horizontal gray limestone and calcareous shale, but little altered, in strata from 1 to 10 feet thick. The road continues up Paddy Creek, and limestone with uncertain dip is seen in places up to 800 feet above Eagle Creek, where it is covered by red and green shale and volcanic breccia of the same colors, containing fragments of old lavas and quartz-diorites. The dip is here probably 10° N., and



A.



B.

TRIASSIC LIMESTONE ON EAST FORK OF EAGLE CREEK.

these rocks continue for a mile or two until the basaltic area is entered a short distance beyond Little Eagle Creek. On the high slopes above, toward Paddys Paradise, strong croppings of limestone are seen.

Between the junction of the forks and Miles Camp, 2 miles below, the series is well exposed in mostly horizontal beds, sometimes faulted, and in places containing strata of interbedded volcanic rocks. Half a mile below the junction is a high bluff, on the east side, which at its base shows horizontal strata of calcareous shale and limestone. Two hundred feet above the creek the strata dip 20° to 30° E., and contain abundant *Halobia* shells and fragments of ammonites. Above the junction, on the east fork, bluish-gray limestone appears in heavy beds and continues in bluffs on both sides of the creek for half a mile. Three miles above the junction heavy limestone bluffs appear on the west side and the rock contains pentagonal crinoid stems and spines of echinoids. Interbedded with this limestone is a volcanic breccia of red and green colors, containing fragments of various lavas as well as of a quartz-diorite. From here on the limestone gradually becomes more crystalline. The trend of the strata is N. 10° E. and the dip probably east, though it is difficult to determine exactly. The highest point reached was about 7 miles from the junction, where, at an elevation of 4,500 feet, an important creek comes in from the west. Above this place the canyon, which has been open with sloping benches in the bottom, becomes narrower, and the mountains rise several thousand feet on both sides. On the west side an enormous white sugar loaf of highly crystalline limestone, containing prisms of tremolite (Pl. LXXVI), reaches an elevation of about 6,000 feet. On the east the slopes are a little more gentle, but the mountains are much higher and consist of heavy masses of dark-green amphibolitic schist showing, high up on the declivities, huge, interbedded, lenticular masses of gray limestone. The strike of the schistosity and also of the bedding is N. 20° E., the dip 60° E. (Pl. LXXV). This schist is the volcanic breccia mentioned above, which has been compressed and made schistose by regional metamorphism. The transition from a series of altered limestone, shale, and volcanic breccias to schists and crystalline limestone is exceedingly beautiful and instructive. The change is rapid and yet gradual. High up at the head of the creek sharp limestone pinnacles rise to elevations of 8,000 feet; granitic rocks are probably entirely absent, though bowlders of this rock were noted in a gulch joining Eagle Creek 5 miles above the junction. A passable wagon road leads up the East Fork from Lily White as far as 7 miles above the junction. From here a very bad trail leads across the mountains into the Imnaha drainage basin.

The girdle of basalt flows of the Columbia River lava which surround the Eagle Range is locally interrupted at the point where Eagle Creek breaks through the foothills. A few hundred feet of basalt overlies the Triassic shales at Sanger, and covers the top of the divide at Lily White. Another area is seen on the slopes between the two forks of Eagle Creek, and isolated basalt knobs are found as far down as Sparta Butte, a conical hill covered with a small patch of this rock. East of Eagle Creek and Sparta the basaltic flows occupy large areas, and the aggregate thickness increases to over 1,000 feet. Here, as elsewhere in the realm of the Columbia River lava, the series is made up of a great number of thin superimposed flows, some vesicular and glassy, others diabasic and massive. Tuffs are absent. The source of the basalt is probably to be found in dikes in the higher parts of the Eagle Range, as is so beautifully shown at Cornucopia, but local eruptions may well have taken place elsewhere. In the Gem mine at Sparta, for instance, a basaltic dike cuts the vein. The time of the eruptions may unhesitatingly be determined as Neocene.

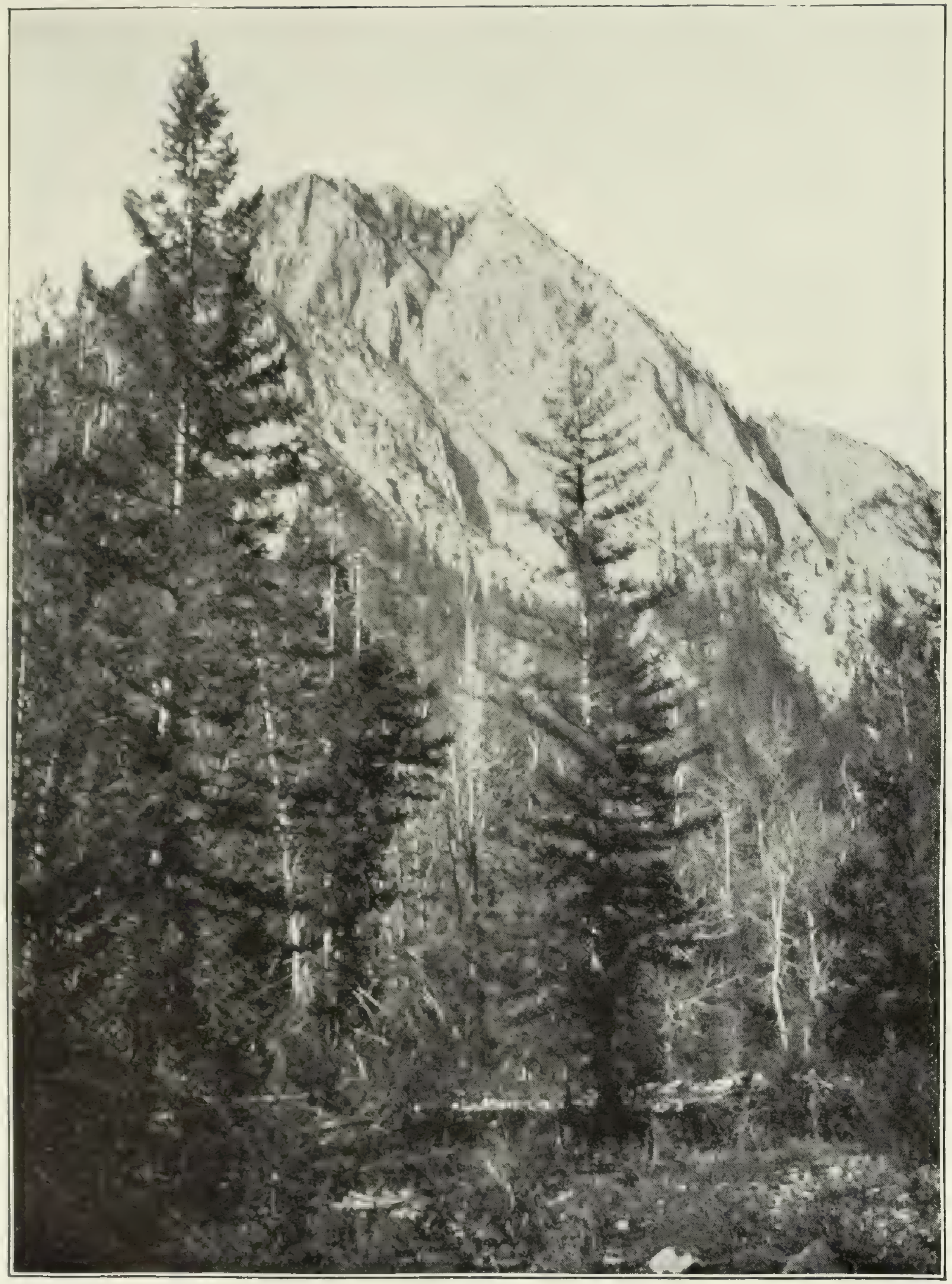
There can be no doubt that glaciers once occupied the upper part of the Eagle Creek drainage, but just how far they descended can not be decided on the present evidence. It is improbable that they extended as far as the junction of the forks of Eagle Creek, and for several miles above the topography suggests rather the gravel flats common below the terminal moraines than the actual presence of the ice stream.

QUARTZ VEINS OF SPARTA.

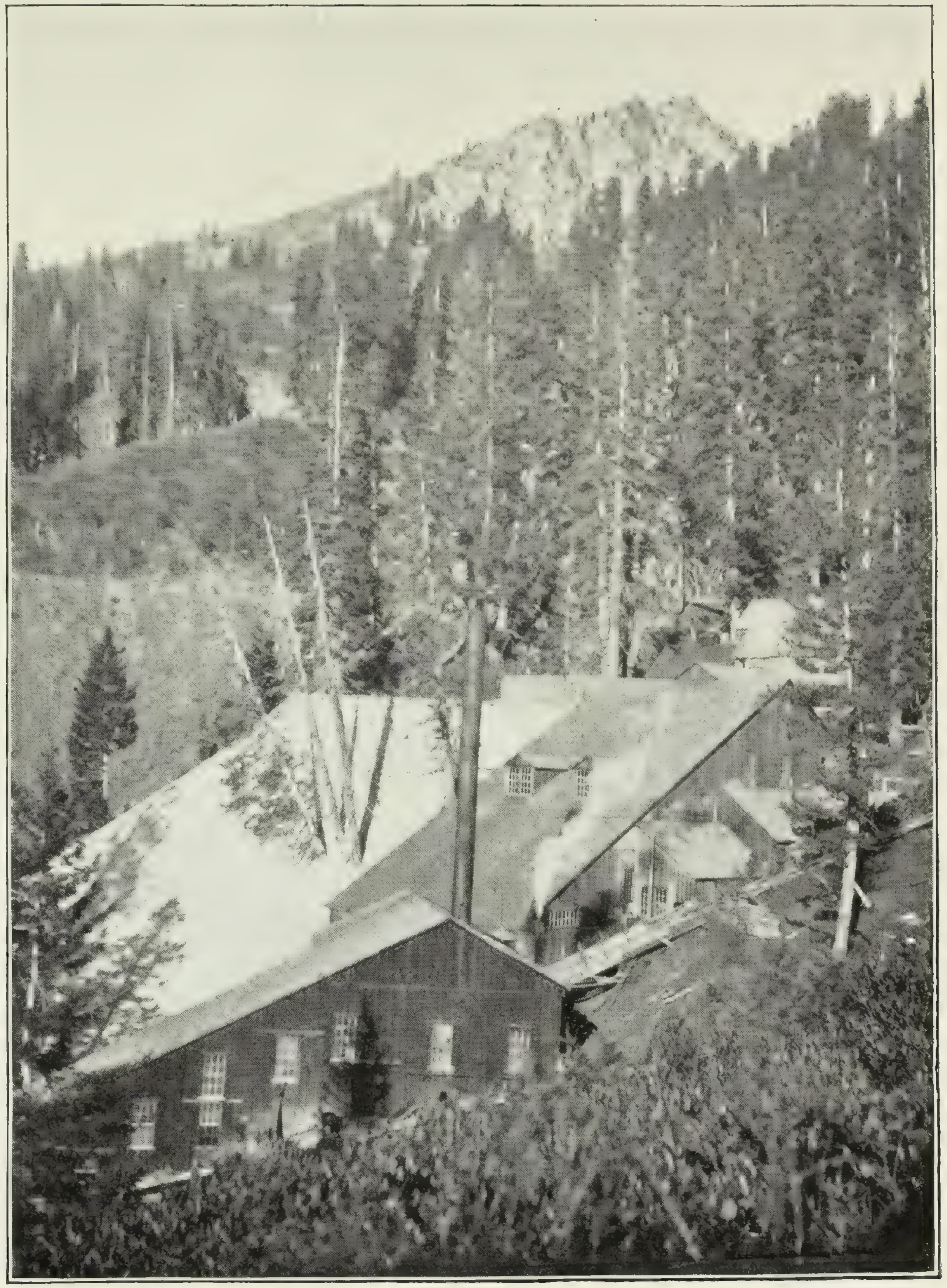
The gulch placers of Sparta in most cases led up to well-defined quartz veins. Many of these were known in early days and gold was extracted by hand mortars, arrastres, and small mills. These operations were not continued, however, and the production from the veins gradually fell off; from $60,000 for Union County in 1880, the output was reduced to $7,300 in 1885, $15,000 in 1886, and $15,000 in 1887; but in 1889 there was a most remarkable change, the output in that year rising to $576,000. Most of this, of course, came from the Sanger mine and the Cornucopia, but a large proportion was contributed by the quartz mines of Sparta. For the four years (1889–1892) from which complete returns are available, the following productions are compiled:

Little Pittsburg	$111,000
Windsor	72,000
Union Tunnel Company	91,000
Gold Ridge Company	124,000
Free Thinker	65,000
Arkansas Belle	83,000
Magpie	19,500
New Gem	59,000
Del Monte	27,500
Buffalo	25,000

As the workings deepened the country rock became harder and the general conditions more unfavorable, so that of late years the produc-



A. LIMESTONE CLIFFS ON EAST FORK OF EAGLE CREEK.



B. UNION-COMPANION MILL, LOOKING WEST.

tion has again been declining, and in 1900 only one mine, the Gem, was worked on a larger scale. Though the veins are narrow they are rich, and it is more than probable that thorough prospecting will develop many good mines in the vicinity. The prevalent strike of the veins is north-south or northeast-southwest; the dip is to the east or southeast. The country rock is throughout a granite, in which the biotite is usually converted to chlorite. The ore is free-milling quartz, with some sulphurets.

The Gem mine, located 2 miles west of Sparta, was worked in early days, a 10-stamp mill being erected in 1873. Two years afterwards the mill was removed to Connor Creek, and the mine was idle for a long time. The vein strikes north-south and its dip is 40° E. The old workings followed the vein to a depth of 100 feet or more on the dip. The new developments consist of a vertical shaft 179 feet deep, with drifts extending 150 to 200 feet from two levels. The vein shows sharply defined foot and hanging walls from 1 to 4 feet apart, between which lie crushed granite and streaks of quartz in some places 2 feet in width. The ore is normal coarse vein quartz, with free gold and a little pyrite and black zinc blende. Near the shaft the vein cuts a dike of granite-porphyry without changing, but on the second level south it is squarely cut off by a basalt dike striking east-west and dipping 50° S., along which some faulting has also taken place. The vein will in all probability be found to continue, as before, beyond the dike.

PLACER MINES OF SPARTA.

A long, heavily timbered ridge follows the western side of Eagle Creek for a long distance toward Powder River. The Sparta mining district occupies the southern end of this ridge, where the rounded hills, here scantily forested, gently slope toward the arid foothills of Powder River. The elevation of Sparta is 4,200 feet. The normal granite which forms the country rock is deeply decomposed and the gulches are filled with gravel. It was found at an early date that these gulches, draining in all directions from the central hill, were auriferous, but on account of lack of water little could be done until, in 1873, the Sparta ditch was completed, with a capacity of 3,000 miner's inches and a length of 22 miles. This canal takes its water from the west fork of Eagle Creek and carries it down on the long ridge to Sparta. Great activity followed its completion, but in a few years the output rapidly diminished. According to the Mint reports the placers produced $35,000 in 1882, $30,000 in 1889, $4,500 in 1890, $3,100 in 1891, $85,000 in 1892. These figures may not be acurate, but they give a general idea of the importance of the district. At present a small production is maintained and much ground is still said to be available on the south slope toward Powder River.

QUARTZ MINES OF SANGER AND EAGLE CREEK.

At the head of Goose Creek, and at an elevation of about 4,600 feet, is situated the Sanger mine, which holds the record as the greatest producer in Union County. The mill is located on Goose Creek, and the mine itself a couple of hundred feet higher, near the divide between that creek and the West Fork of Eagle Creek. The vicinity constituted the old placer camp of Hog'em, and from the gulches leading up to the mine the sum of $500,000 is reported to have been extracted. The principal vein, called the Summit lode, was discovered in 1870 and actively worked during the following years. In 1874 the production was $60,000, from ore containing $16 per ton. Just how much was produced up to 1887 can not be ascertained, but it is not probable that the amount was very great. In 1887 a 10-stamp mill was built, and in 1889 the production began to increase rapidly. During the four years 1889–1892 the Mint reports give a total of $813,000 for this mine. Work was discontinued in 1897 and the mine was idle until December, 1900, when preparations were made to reopen it. What the total production has been is difficult to estimate. It is commonly given as $1,500,000, and this figure is very likely approximately correct.

The developments consist of several tunnels and an incline shaft 400 feet deep. Unfortunately there was no opportunity to examine the deposit, so that the information available is scanty.

The country rock is a black clay slate, containing pyrite near the veins. The latter are well-defined quartz veins, with clay selvage, and dipping at gentle angles. To judge from available specimens, the ore is a normal coarsely crystalline vein quartz, with a little gray calcite. It contains about 3 per cent sulphurets, consisting of pyrite, chalcopyrite, brown zinc blende, and a little galena, together with free gold. On the whole, it has considerable similarity to the ores of many California gold-quartz veins. The principal vein is said to contain three pay shoots. The upper stopes were worked for a horizontal distance of 600 feet, 50 to 100 feet below the surface. The average width of the vein was here 15 inches and the ore yielded $20 to $25 per ton. Below the zone of surface oxidation the vein was from 2 to 4 feet wide and the ore yielded $12 per ton. If these figures are reliable it may mean that the oxidized vein has been leached and compressed to smaller volume; while the absolute amount of gold remained the same the tenor appeared to be increased by this process.

Several other mines and prospects have been discovered in this district. Among them are the Basin claims, a few miles northwest of Sanger, which have been small producers. Three miles southeast of Sanger is the Snowstorm, cropping in greenstone, striking northeasterly and dipping 30° NW., developed by a 160-foot incline. Some rusty quartz was extracted and milled in the arrastre at Lily White.

The Lily White is situated 4 miles southeast of Sanger, on the divide between Eagle and Goose creeks, has the same strike and dip, and crops in argillite country rock. The production is small.

Four miles south-southeast of Lily White, on the same divide, is the Dolly Varden. This is a big outcrop of rusty quartz and silicified shale, developed by irregular surface cuts and pits. No regular vein could be recognized. The Mint reports credit this locality with a production of $115,000, probably contained in rich pockets.

Several claims are located on the east fork of Eagle Creek. About 10 miles up from the forks Miller and Lane have been running an arrastre for several years. Two miles up from the forks is Cady's mill, with 10 stamps. This was partly supplied from a gold-quartz vein in Triassic sedimentary rocks above the mill, but most of the ore came from the Sheep Rock mine, located 1 mile farther up the creek and 1,000 feet above it on the west side. A considerable amount of gold was formerly extracted here. The Mint report for 1892 credits $29,400 to this mine. The country rock is a Triassic volcanic breccia, the ore normal vein quartz with chalcopyrite and presumably free gold.

Bornite in quartz, said to come from the contact of limestone and igneous rocks has been found in this vicinity. Another arrastre is located on Paddy Creek at the White claim, 3 miles southeast of the Lily White.

PLACER MINES OF SANGER AND EAGLE CREEK.

The old placers of Sanger have already been mentioned. Shallow placers also occur on the road 2 miles west of Sanger mill and are occasionally worked.

The placers of Eagle Creek have been worked at least since 1869, and each summer more or less mining is still carried on. The total amount extracted from these placers is probably considerable, but estimates are very difficult to obtain. In 1869 the district was known as the Cooster and 250 men were working in it. All along Eagle Creek are benches of heavy gravel, 50 to 100 feet above the stream; they are not large, however, and contain heavy bowlders, making the work expensive. In 1900 hydraulic work on a bench of this kind was proceeding on a small scale near Martin's camp, half a mile above the forks of the creek. A year or two ago it was proposed to handle this gravel on a large scale, but the attempt was abandoned.

Near the forks drift mining has been carried on underneath the gravel benches. Similar and more successful drift mines are located at Miles's camp, 1½ miles below the forks. Finally at Martin's, still farther down, where the Cornucopia road crosses Eagle Creek, small placers have been worked for a long time.

Placer mines are also found on upper Paddy Creek and at Paddys Paradise, which are credited with a production of $43,000 between 1889 and 1892. The present annual output of the placer mines of the Eagle Creek district is probably only a few thousand dollars.

CORNUCOPIA MINING DISTRICT.

GENERAL FEATURES.

The town of Cornucopia, which in recent years has become the home of a promising mining industry, is situated in the Eagle Creek Range not far from the head of Pine Creek, and at an elevation of 4,700 feet. In air line it is 36 miles northeast of Baker City, but by the devious ways of the mountain roads the actual distance is more nearly 55 miles. Pine Creek drains about 3,500 square miles of the basaltic plateau at the eastern foot of the Eagle Range. Cornucopia is located on the west fork of the stream, 7 miles above the little agricultural town of Carson, at the upper end of the fertile Pine Valley. From Carson the road ascends a narrow canyon through the basalt plateau. At Cornucopia the creek forks. The underlying older rocks rise from below the covering lavas and form ridges and peaks attaining elevations of from 7,000 to 9,000 feet above the sea. It is an impressive region of deep canyons and precipitous slopes, and the geological features are not less striking than the topographic forms (see Pls. LXXVII and LXXVIII).

GEOLOGY.

The older rocks exposed at Cornucopia are granodiorite and micaceous schist. The granodiorite, which occupies a large part of Granite Mountain to the west of Cornucopia, is a light-gray, granitic, fairly coarse granular rock, consisting of andesine feldspar, orthoclase feldspar, biotite, and quartz. In places the prevalence of plagioclase and hornblende makes the rock assume the aspect of a diorite. A few small dikes of pegmatite or aplite are contained in the granodiorite. This rock is well exposed at the Union-Companion mine, in the high peak rising above it (Pl. LXXVI, *B*), and also in the upper part of Bonanza Basin (Pl. LXXVII, *B*).

The predominant rock is a dark-gray to greenish micaceous amphibolitic schist, weathering reddish or brownish, and contrasting strongly with the gray granodiorite. The schist borders the granodiorite with exceedingly irregular contact, and is well exposed at the Red Jacket, Emmet, and Last Chance mines. Dikes of granodiorite are found in the schist, which is thus clearly the older rock. Brownish schist occupies the whole of Simmons Mountain between the forks of the creek, and also most of the very rough country at the head of the west fork, culminating in Cornucopia Mountain, the highest point in the range. The general strike of schistosity appears to be north-south, the dip 70° E. At the Red Jacket mine the schist is a fine-grained biotite-feldspar-quartz rock with rough cleavage. It is very similar to certain contact-metamorphic rocks or "hornfels." But little attention could be devoted to the schist area. It would not be surprising, however, if

A. EAST FORK OF EAGLE CREEK, LOOKING UPSTREAM.

B. BONANZA BASIN, NEAR CORNUCOPIA.

these rocks should prove to be Triassic sediments and lavas altered by regional metamorphism, like those of upper Eagle Creek.

The Columbia River lava is a very prominent feature of Cornucopia geology, and the exposures are particularly interesting, giving an excellent clue to the manner of eruption of these enormous basalt flows. The road from Eagle Creek enters the area on the divide between that stream and Pine Creek. Emerging from the dense forests, one obtains a magnificent view from the basalt bluff, 1,000 feet high, overlooking Pine Valley. Long ridges of monotonous brown lava beds surround this fertile oasis, and, a little more heavily forested as the elevation increases, they cover the whole eastern slope of the Eagle Mountains up to elevations of 6,000 or 7,000 feet. Another fine view is obtained from a point near the Last Chance mine at Cornucopia. The heavy lavas extend right up to the Union-Companion mine, and rise, leaning against Granite Mountain, to an elevation of 6,200 feet. The town of Cornucopia practically stands at the contact of granodiorite and lava, at an elevation of 4,700 feet. On looking up the east fork of Pine Creek the lava beds are seen forming its east wall up to the very divide. Their highest flows slope gently eastward and lean against the older rocks, at an elevation of 7,500 feet.

The character of this remarkable lava formation is the same here as elsewhere: A series of dark-brown superimposed flows, each from 20 to 150 feet thick, and distinguishable by slightly different weathering, due to slightly different texture. Tuffs are absent. The rocks are fine-grained to glassy olivine-basalts, some of them extremely vesicular, and there can be no doubt that they were poured out as subaerial flows, gradually piling up to their present depth. Rocks in the bottom of Pine Creek Canyon, a mile below Cornucopia, are likely to be as vesicular and glassy as those found 800 feet higher up in the series. The course of the contacts shows that the basalt was poured out over an extremely rugged mountain side scored by deep ravines. These ravines were filled by the lava, and, in many cases, the same gulches have been again excavated by post-basaltic erosion.

The question of the mode and locus of eruption of the Columbia River lava has long been a matter of much interest. A partial solution of the problem is found at Cornucopia. It was to be expected that the source of these flows, which encircle the base of Eagle Range as a somber mantle, should be found in the mountains, in spite of the absence of the ordinary topographic forms of volcanic centers of eruption. And it is found, indeed, that the old rocks near Cornucopia, the granodiorites and the schists, are cut in every direction by numberless dikes, through which the lavas once poured out—a liquid, basic magma pressed out in quiet flows accompanied neither by explosive action nor by ashes, breccias, or tuffs. Numerous dikes cut Simmons Mountain, but they are less clearly visible on account of the dark-gray color of the schists, and similar dikes cut the high granite hill above the Union-Companion mine.

A fine 10-foot dike cuts the granodiorite on the scale platform 200 feet above the Union-Companion mill. Others, 50 feet wide, are seen on the Red Jacket claim. But nowhere are they developed on such a magnificent scale as in the rocky glacial cirque of Bonanza Basin (Pl. LXXVII, B).

Two long straight basalt dikes, from 10 to 30 feet wide, cut across the basin with a strike of N. 30° E. and an easterly dip of 70° to 80°; this is perhaps the prevalent direction, but there are other dikes running east-west or even curved and irregular. One of the latter kind descends the slope in a curve and is squarely cut off by the upper of the two straight dikes, which also possesses a very marked jointing, perpendicular to its walls. Other more coarse-grained basalts weather in rounded outcrops. The rocks are greenish gray to dark gray, of fine to medium grain, and not vesicular; they are normal basalts, with or without olivine. Most of them contain but a small amount of glass, and some have a well-marked diabasic granular structure.

The basalt dikes are younger than the gold-quartz veins and frequently cut and fault the latter.

The Pleistocene deposits of Cornucopia consist chiefly of moraines and glacial débris. Above Carson a gravelly and bowldery deposit, 200 to 300 feet wide, covers the bottom of the canyon. A well-marked terminal moraine is met with 3 miles above Carson at an elevation of 4,250 feet. Above this, glacial material is abundant.

GOLD-QUARTZ VEINS.

General statement.—The mines of Cornucopia were discovered comparatively late; very little was reported from this district until between 1880 and 1885, soon after which production began. In 1889 the district was credited with $74,000 and since then an output has been steadily maintained. The camp has passed through various vicissitudes and much money has been unwisely spent. Even at the present time the industry is not established upon as firm a basis as it ought to have, for without doubt it is a district of great promise and should yield good returns from capital judiciously invested.

The producing veins are all situated from 2 to 3 miles east to north of the town and at elevations ranging from a few hundred to 3,000 feet above it. Prospects have also been found on Red Mountain, at the head of the west fork of Pine Creek, several miles above Cornucopia, but these are not, as yet, much developed. At least five principal veins may be distinguished; one of these is on Simmons Mountain, the other west of the creek. The strike is in general north-south, but with directions slightly converging northward. The dip on Simmons Mountain is eastward, while the other veins dip west at moderate angles. The veins are simple, sharply cut fissure veins with a filling of quartz and sulphurets; the ore is, to a great extent, free milling.

Union-Companion mine.—One of the principal veins of the district is that passing through the Union-Companion and Red Jacket claims. These properties, together with the Last Chance vein, described later, and many other outside claims, are owned and operated by J. E. Searles. During 1900 the Union-Companion was the only mine worked on a large scale in this vicinity. Before the present owner acquired it, in 1894, it was operated by the Oregon Gold Mining Company, of Louisville, Ky.; much money—$500,000 it is reported—was spent on it, and a 20-stamp mill was erected with pan amalgamation, according to the Boss continuous system. Being entirely unsuited to the character of the ore, this process was soon abandoned and plate amalgamation, concentration, and chlorination substituted. Shortly after the present management acquired control, chlorination was given up, proving more expensive than shipping to smelting works. The principal expense of mining in the district is the heavy freight charges over 50 miles of bad road. At present the ore is crushed by a 20-stamp mill with 12 vanners, for which an electric power plant has lately been installed. The mill and principal working tunnel are located near the head of Fall Creek, 1 mile northwest of Cornucopia, at an elevation of 5,700 feet.

The total production can not be ascertained, but it is scarcely probable that it has reached $100,000 in any one year since the beginning of operations, about 1888. In 1889 production from this vein reached $79,400; in 1890, $11,300; in 1891, $20,800; in 1892, $21,700. The total production for the three claims may, with some probability, be estimated at $600,000. The Red Jacket, actively worked for several years after 1889, is now idle.

The total developments at the group probably amount to 10,000 feet of shafts and tunnels. The present workings are accessible through a crosscut 1,000 feet long, 300 feet below the Union croppings. Near the point where the vein is struck an incline shaft is sunk 200 feet long on the dip of the vein and the deposit opened by drifts on two levels.

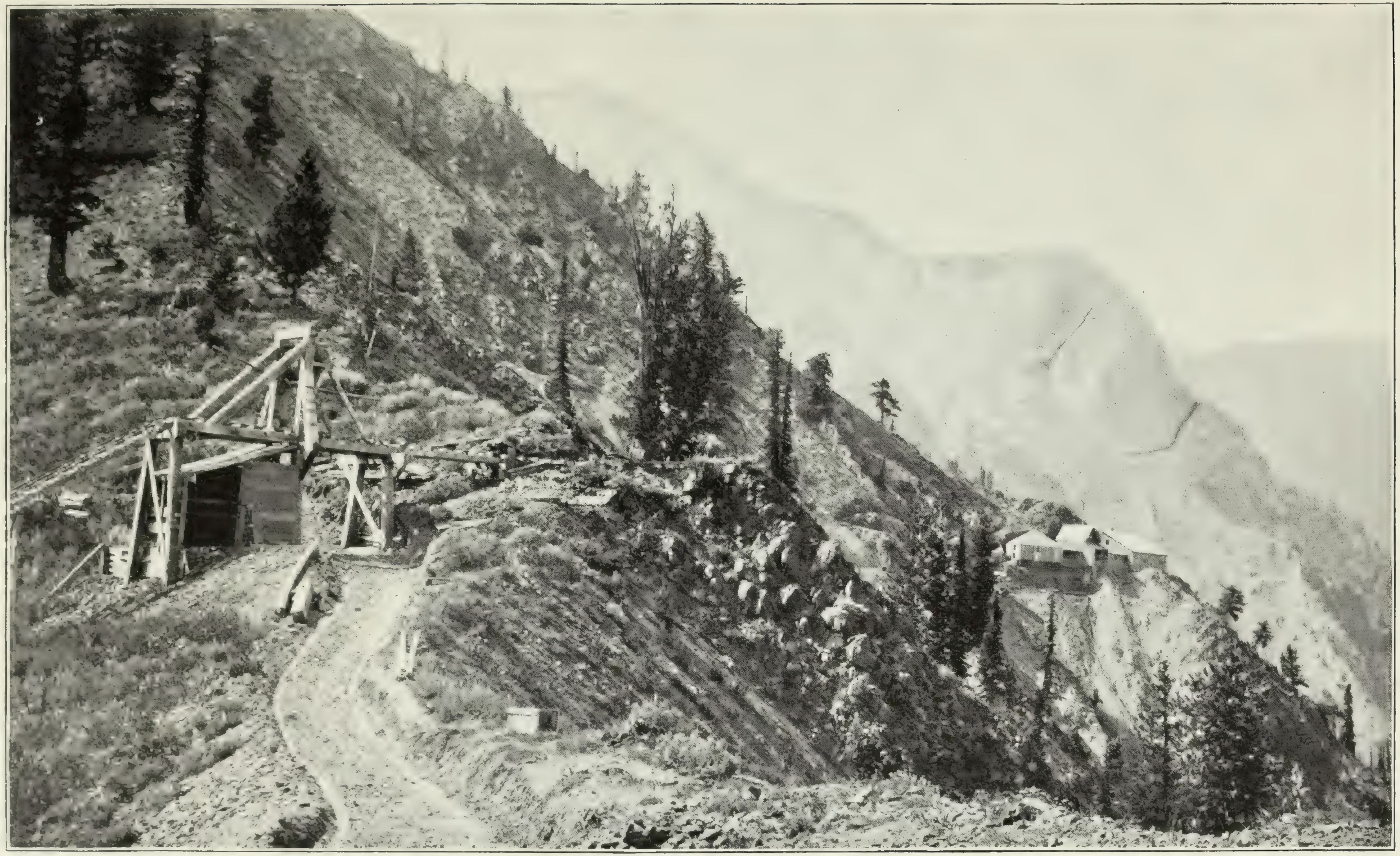
The crosscut traverses 600 feet of basalt before meeting the granodiorite. The contact seems very sharp, and is accompanied by a breccia, so that it seems possible that we have here a flow directly associated with a neck or dike. The vein is contained in granodiorite. On the south side below the crosscut the vein is unbroken, but on the north side on the first and second levels it is badly cut and somewhat faulted by basalt dikes up to 50 feet wide. Similar dikes cut across the vein at the Red Jacket tunnels, where the schist area begins.

The vein strikes a few degrees east of north and dips 40° W. Its outcrops were plainly marked, though not conspicuous. The width is from 2 to 5 feet, though occasional pinches occur. On the whole, the vein is remarkably persistent. Hanging and foot wall are sharply marked, inclosing a massive vein of white normal quartz from 2 to 4 feet wide. A ribbon structure by shearing is usually developed in the lower part of the vein, or at least for a few inches from the foot wall. Pl. LXV, *A*, from a photograph taken in the stopes above the second level south, well illustrates the character of the vein. It is extremely similar to some of the simpler quartz veins of Nevada City and other parts of California. Free gold is rarely seen, but from 10 to 60 per cent of the assay value is recovered on the plates, the bullion having a fineness of 870. The sulphurets, amounting to from 2 to 7 per cent, are irregularly scattered through the quartz and consist chiefly of pyrite, with smaller quantities of galena, zinc blende, chalcopyrite, and arsenopyrite. Ordinarily the richness of the ore is in proportion to the quantity of sulphurets contained. There is very little silver in the ore. The concentrates run from $150 to $200 per ton, the latter containing 9 ounces of gold and 50 ounces of silver per ton. Tellurides are said to occur in the ore, but none were recognized in the specimens collected. The average value is $15 per ton, of which 85 per cent is recovered. While fresh granodiorite often adjoins the vein, it is usual to find 1 or 2 feet of highly altered rock on the foot wall. This light-gray, soft material contains little pyrite and has ordinarily no value, but consists of quartz, sericite, and much calcite, indicating an entirely normal sericitization and carbonatization, similar to that of the California gold veins. The principal pay shoot dips south and is now worked to the south of the shaft.

As in all of the Cornucopia veins, the surface oxidation plays a very small part, probably owing to the recent glaciation, which has removed the upper and softer parts of the vein. Normal unaltered quartz is found a short distance below the surface.

Robert Emmet mine.—Northward from the Red Jacket shoot the vein pinches in the hard schist of the backbone of the ridge, but opens again in the Emmet claim, which has been worked successfully on a moderate scale since 1899. A tramway connects it with a mill built in Elk Creek. The elevation is 6,350 feet. The developments consist of a shaft 165 feet deep on the incline, drained by a tunnel, and of drifts on two levels. The vein is similar to the Union-Companion, though only 1 to 2 feet thick. It contains a shoot of good ore; some of the partly oxidized ore near the surface, 100 feet south of the shaft, contains up to $100 per ton (Pl. LXXVIII).

A short distance below the Emmet is the Bryan claim, on which a few years ago a pocket containing $7,000 of very rich telluride ore was found. Subsequent operations have not developed anything of value. The telluride is a silvery, ductile sylvanite, covered by a film of dull-brownish gold and inclosed in normal vein quartz.



ROBERT EMMET MINE.

Last Chance mine.—This is located on a parallel vein 1,000 feet higher than the Union-Companion mill, at an elevation of 6,700 feet, and is connected with the mill by a winding and dangerous road, down which the ore is hauled by teams. The output is as yet not great, but the mine promises well if properly developed by tunnels. The present developments consist of a tunnel 400 feet long, an incline 200 feet long on the dip of the vein, together with 200 feet of drifts on the 100-foot level. There is an excellent opportunity to develop this vein by deep tunnels.

The vein fills an extremely well-defined fissure dipping 45° W., and consists of 5 to 6 feet of massive, coarse-grained vein quartz. The terminals of the quartz crystals often project in cavities. As far as exposed, the same width of solid quartz is maintained. Through the quartz the sulphurets are scattered irregularly; they consist principally of pyrite, with a little chalcopyrite and zinc blende. The ore is said to average $23 over the whole width. Near the vein the micaceous schist which forms the country rock is bleached and sericitized.

Other veins.—A third vein system cuts across Bonanza Basin and is accessible by trails from the Last Chance mine. None of the many claims has been extensively developed. At the Queen of the West short tunnels expose a sharply defined quartz vein, 1 to 2 feet wide and containing pyrite and chalcopyrite. On the Wild Irishman, near the summit of the mountain, the same or a parallel vein is exposed, with a large body of medium-grade ore. Two miles north of Cornucopia, on the long ridge between the East and West forks, are the several claims of the Simmons vein. This is reported to be an extremely sharply defined quartz vein striking north-northwest, but dipping east, in contrast to the veins on the other side of Pine Creek. The developments consist of several tunnels and shafts, the latter 100 to 200 feet deep. Good pay shoots with rich pockets are said to exist, but for some reason active work has not been taken up.

PLACER MINES.

While there are no placer deposits at Cornucopia, gold-bearing gravels form the bottom of the canyon just above Carson and below the terminal moraine, and shafts have been sunk in this gravel 1 mile above Carson. The amount of heavy bowlders in the gravel would render placer work difficult and expensive.

PINE CREEK AND LOWER POWDER RIVER.

COLUMBIA RIVER LAVA.

East of Cornucopia and Sparta extends a very large area of Columbia River lava. It connects westward by a narrow strip along Powder River with the great flows north of Medical Springs. It also crosses

Snake River and extends, south of the Seven Devils, for 40 miles eastward into Idaho. Northward it is apparently continuous for over 100 miles, extending up to and beyond Lewiston. The area forms a table-land of varying elevation. Near Carson it rises to 4,200 feet; at Sparta it is only 3,500; along the lower Pine Creek it probably averages 3,500 or 4,000 feet; but farther north, on the divide between Pine Creek and the Imnaha, it rises to elevations of from 6,000 to 7,000 feet, and extends from Snake River Canyon to the foot of the Eagle Creek Range. This is the prominent plateau seen across the river from the Seven Devils and figured in a preceding report.[1]

Throughout the larger part of the area the formation consists of a great number of superimposed flows well exposed along many sharply incised canyons. On Pine Creek, a few miles up from Snake River, about thirty flows were counted in a bluff 1,800 feet high. Owing to slight differences in texture, weathering brings out the structure in an excellent manner. Most of the rocks are normal olivine-basalts with dark-brown glass, but some flows show a fine-grained, diabasic, granular structure without glass.

LAKE BEDS AND COAL.

Along the foothills of Eagle Valley, at elevations of 2,300 to 2,500 feet, appear light-colored sands, tuffs, and clays, sometimes also coaly material; these apparently indicate deposition in a lake basin, but were not further investigated. All along Powder River, upstream from Eagle Valley, the basalts are interstratified with tuffs and sediments. At the mouth of Goose Creek, on the south side of the river, opposite Love's ranch, prospecting operations have been carried on for coal. The developments are 200 feet above the river in rolling foothills and consist chiefly of a gently sloping incline, 100 feet long, at present full of water. Dioritic bed rock is not far below the surface. In another cut the coal seam was exposed, showing 2 feet of a poor quality of shaly, crumbling lignite, underlain by tuffaceous clay and covered by a thin seam of clay, above which rested a basalt flow. The clay and coal are thus clearly intercalated into the volcanic series. Prospecting by boring above these inclines has been undertaken, but apparently without success; and, indeed, the chances of developing a paying coal bed seem very slight.

PLEISTOCENE.

In this large area of volcanic beds the Pleistocene period is represented by few deposits. Narrow bars occur along Snake River and Pine Creek, but rarely rise more than 50 feet above the stream. In many cases these small areas are covered with excellent soil from decomposing lavas, and the mild climate is favorable to horticulture wherever water is obtainable. The only alluvial areas of importance in this vast extent of pastures and forests are those of Pine and Eagle valleys, both of them dotted with beautiful fields and orchards. Pine Valley, in the middle course of Pine Creek, is 10 miles long and up to 3 miles wide, with elevations ranging from 2,500 to 3,400 feet.

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[1] Twentieth Ann. Rept. U. S. Geol. Survey, Part III, 1900, Pls. XIV and XV.

Eagle Valley, at the confluence of Eagle Creek and Powder River, is eroded in the soft lake beds and tuffs deposited in this vicinity. The elevation is a little lower than Pine Valley, reaching only 2,200 feet. Between Eagle Creek and Powder River a flat-topped ridge rises to an elevation of about 3,300 feet; from here to Sparta extends a continuous gentle slope. This whole ridge consists chiefly of coarse gravels of both older rocks and Neocene basalts. It is clearly the deposit of a post-Neocene stream corresponding to the present Powder River, and was made at a time when the main drainage level stood about a thousand feet higher than at present. The elevation of 3,300 feet clearly marks an old base-level. These gravels should probably be considered as of late Neocene age.

COPPER DEPOSITS OF SNAKE RIVER.

GENERAL FEATURES.

Under this heading will be described a number of recently developed copper prospects in the canyon of Snake River, southwest of the Seven Devils and extending from the mouth of Pine Creek 12 miles northward at least, to Eckles Bar. Snake River here flows in a rather open canyon from 2,000 to 5,000 feet deep. The slopes are not as precipitous as farther north, and they are covered by abundant bunch grass. Forest growth does not appear below an elevation of 4,000 feet. No important tributaries join the river for a long distance north of Pine Creek. The swift and yet smooth river which has excavated this wonderful trench since the Neocene period pursues its course in a rocky channel a few hundred feet wide and in places very deep. A few small gravel bars and alluvial cones from tributary canyons form the scant amount of agricultural land available. The color of the water, here as above, is a peculiar light green, no doubt due to the suspended fine sediments of the lake beds of the upper valley. The climate along the river is comparatively warm, and very little snow falls during the winter.

This isolated country is reached by wagon road from Baker City via Pine, a total distance of about 80 miles, or by wagon road from Salubria, Idaho, via Cuprum, in the Seven Devils, and the so-called Kleinschmidt grade, which in many serpentine curves descends the canyon slope to Ballards Ferry.

Much has been said regarding the possibilities of navigation on Snake River. The many rapids encountered make the distance between the mouth of Burnt River, near Huntington, and Ballards Ferry practically unavailable for navigation, and to improve the channel would be extremely costly. About 1892 the stern-wheeler *Norma* was built by the owners of the Peacock mine, who also constructed the Kleinschmidt grade. The steamer, which was 150 feet long, made two trips between the points mentioned, but came to grief on the second trip. After repairs, the steamer was taken down through the canyon to Lewiston, a most dangerous but successful undertaking. About 1896 a small appropriation was made by Congress to improve the channel of the river. Some rocks were blasted out and the money was expended, but the work done was of little value compared with the number and extent of the rapids. In 1898 the steamer *Mabel* was built by the Northwestern Copper Company, which was then attempting to open the Peacock mine. The steamer was 100 feet long. The engines are said to have been too weak for the size of the boat. At any rate, the *Mabel* made sixteen trips during periods of high water between Ballards and Huntington. Going down the river was not difficult, but returning, the steamer had to be towed at from eight to twelve places. Finally the steamer was wrecked, and now lies stranded near the mouth of Powder River. Navigation between Huntington and Ballards is possible only during three months of the year.

Regarding the river below Ballards, navigation is there even more impracticable. No steamer has ever come up from Lewiston, and this feat is, indeed, believed to be impossible. The worst rapids are at the mouth of Deep Creek, below the Seven Devils.[1]

GEOLOGY.

For a long distance above the mouth of Pine Creek the canyon is cut entirely in the flows of Columbia River basalt, but a short distance below the point mentioned the older rocks emerge from below this cover of igneous flows. On the west side the latter continue for many miles northward, forming the upper wall of the canyon slope, well marked by its brown color and lines of volcanic flows. At the Iron Dike mine the contact runs 1,000 feet above the river, at Ballards about 2,000, and at Spring Creek about 1,800 feet above the stream. The thickness of the volcanic flow is from 2,000 to 2,500 feet. On the east side the contact follows more or less closely the course of Indian Creek, and near Cuprum bends eastward. A great mass of older rock is thus exposed on the Idaho side, culminating at White Monument Peak, which rises 6,400 feet above the bottom of the canyon. The ridge between Indian Creek and the river north of Cuprum is called Horse Mountain.

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[1] For a report on the Snake River between Huntington and Ballards Ferry see Ann. Rept. Chief of Engineers, U. S. A., 1891, Part V, p. 3285.

In the older series the predominant rocks are greenstones of various kinds, ranging from metabasalt to metarhyolites, and frequently containing roughly bedded masses of tuffs and breccias. These igneous rocks are old lavas erupted during the Triassic period. Though greatly altered, they have rarely been much compressed or acquired schistose structure. Embedded in those volcanic flows are smaller streaks of sedimentary rocks.[1] These consist of black clay slates and bluish-gray limestones, neither extremely altered. On the Kleinschmidt grade, 2 miles west of Huntley's ranch, at an elevation of 3,800 feet, limestone and shale crop with northerly strike; more limestone is found northwest of this place, in Lime Peak Gulch; finally, a heavy mass of limestone crosses the river between Spring Gulch and Eckles Bar. On the slopes a mile west of Ballards a band of clay slates crops with northeasterly strike. In the latter Mr. E. Antz, of Ballards Ferry, found flat impressions of shells which Dr. T. W. Stanton informs me are large *Halobia* or *Daonella*. In the limestone mass 4 miles below Ballards fossils have also been found. A piece of this limestone given to me by Mr. Antz showed a *Lima*, with fragmentary imprints of a *Halobia* or similar form. These finds place the series, without much doubt, in the Triassic. During a reconnaissance in 1897 a number of round crinoid stems were found in the limestone on the grade 2 miles west of Huntley's ranch, mentioned above, and the belief was expressed[2] that the series was Carboniferous; it was thus indicated on the accompanying map, the doubtful character of the determination being emphasized by a question mark in the legend. From the present data the rocks are Triassic, and this is also confirmed by the great similarity to the Triassic series of Eagle Creek (see p. 581).

COPPER DEPOSITS.

A great number of copper deposits have lately been discovered in this district, and active prospecting is proceeding. Ordinarily they have the character of impregnations along certain lines in the old greenstones. While these deposits may represent lines of fracture, they have only exceptionally the features of clearly defined fissure veins. The ores are chalcopyrite, bornite, and chalcocite, the gangue epidote and quartz. The deposits are not at all similar to the contact type characteristic of the mines of the Seven Devils and described in a previous report.[3]

Iron Dike.—This is a copper deposit discovered in 1897, on which developments have recently been undertaken by the Northwest Copper Company. It is situated on the west side of Snake River and about 2,000 feet distant from it. The croppings are 675 feet above the river and 375 feet above the lower tunnel which now is being driven, expecting to crosscut the deposit 800 feet from the mouth. The uppermost tunnel is 70 feet lower than the croppings, and there is an intermediate crosscut 120 feet below the same.

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[1] Compare Twentieth Ann. Rept. U. S. Geol. Survey, Part III, 1900, pp. 88 and 251.

[2] Twentieth Ann. Rept. U. S. Geol. Survey, Part III, 1900, p. 86.

[3] Twentieth Ann. Rept. U. S. Geol. Survey, Part III, 1900, p. 251.

The prevailing country rock is a chloritic, indefinite greenstone, without schistose structure. The microscope shows it to be an extremely fine-grained igneous rock with streaks and spots of chlorite, as well as abundant but very minute fibers of sericite; the groundmass is probably an intimate mixture of chlorite and feldspar. At the end of the upper crosscut a dark-brown, much altered metaandesite occurs. The croppings are large masses of black and brown stained rocks, one knoll rising 75 feet above the general slope and measuring 100 feet across. It is said that the croppings can be traced for some distance in a west-northwesterly direction. At any rate, few walls or fissures can be seen; one near the mouth of the highest tunnel strikes north 55° W. and dips 60° S. The maximum width of the croppings is probably 200 or 250 feet. On the rusty surface of the croppings scarcely any copper stain indicates the heavy body of chalcopyrite immediately underlying it. Holes a foot or two deep show somewhat decomposed pyrite, but very little chalcopyrite, the latter appearing only a little farther below the surface. The upper tunnel, for the first 100 feet, is in heavy ore of mixed chalcopyrite and pyrite; then follows 80 feet of poorer ore. A sharp contact here separates the chloritic greenstone from the dark-brown metaandesite. Crosscuts extending 25 feet each way in the best part of the ore show a width of 4 feet of solid sulphides which may average 15 to 20 per cent in copper. The largest part of the tunnel is, of course, in poorer ore, consisting of disseminated pyrite and chalcopyrite in chloritic greenstone. There are also abundant quartz seams, veinlets, and nodules which contain chalcopyrite, and often a regular silicification of the rock may be noted. Zinc blende or galena rarely occurs, and a little antimony is contained in the best ore. The ore contains about $2 in gold and 6 to 30 ounces silver per ton. These amounts are apparently independent of the percentage of copper. The intermediate tunnel, 150 feet long with a crosscut 125 feet toward the west, also shows a heavy body of sulphides.

If the lowest crosscut, now being driven, exposes similar bodies of ore the deposit will be of considerable value. At present, owing to lack of development, it is not easy to form a positive idea of the character and prospects of the property, but there can scarcely be any doubt that it is a zone of crushing in which copper-bearing solutions have deposited their contents, largely by processes of replacement.

Near the Iron Dike, on both sides of the river, are many other prospects showing similar ores.

River Queen.—This deposit is situated on the Idaho side, half a mile above Ballards. The croppings are 250 feet above the river. The developments consist of a crosscut 200 feet long, 100 below the croppings, and 100 feet of drifts on the vein. The rock is a greenish metarhyolite, with large corroded quartz crystals. In places it is distinctly silicified, but contains also in other places some sericite and calcite, as well as much chlorite. Near the end of the crosscut are two ore streaks, striking northeasterly. The first, a fairly well-defined seam with steep dip, shows a few inches of copper ore, chalcopyrite, or oxidized ore associated with silicified country rock; the second is in places several feet wide, but is not connected with any clearly defined fissure, often branching and rapidly changing in width. The ore is here cuprite and malachite, the former rich in silver.

Other prospects.—There are many other prospects near Ballards. In most of the gulches copper-stained float may be found, and deposits have been located on both sides of the river. One of these is situated in the gulch just south of the first bend of the Kleinschmidt grade, 500 feet above the river. In addition to oxidized copper ore, this prospect contains a little galena and zinc blende. Other deposits are found in McKinley Gulch above the grade.

A number of deposits are reported from the Oregon side of the river 5 miles below Ballards, at the mouth of Spring Creek. A string of claims is here laid out, following the contact of a large limestone mass from the river up to the covering flows of Columbia River basalt. These were not visited.

Copper King group.—This group of claims is situated 2 miles below Ballards, on the Oregon side, at a place known as McDougals Camp. The prevailing rock is the usual greenstone or old and altered Triassic lava. Here, however, it is very amygdaloidal, the cavities being filled with white or reddish calcite. The microscope shows it to be a meta-andesite containing much chlorite.

The Copper King prospect presents a fairly well-defined vein in tuffaceous amygdaloid rock, striking N. 70° W., dipping 45° N., and traceable for a few hundred feet. The ores are bornite, with some chrysocolla, accompanied by much epidote and a little quartz. The quartz seems to be shattered and silicified rock rather than a simple filling.

The Harvest Queen is another prospect 1,500 feet above the river. This a small but well-defined vein up to 1 foot thick, striking N. 20° E., and dipping 50° E. It is said to be traceable into the adjoining claim, Cap. Miller. The clearly defined filling consists of normal vein quartz, much epidote, and heavy masses of chalcocite.

A thousand feet above the river, between the two prospects already mentioned, is the Golden West, with several extensions, most prominent of which is the Leonard. These claims have a northwesterly direction, following the ore streak, which is not a well-defined vein, but probably a crushed zone in which the amygdaloid is impregnated with copper glance, always accompanied by microscopic epidote. As usual, there is much calcite in veinlets and nodules. This zone is well marked for half a mile or more, and its width is from 10 to 30 feet. Hardly any copper stain is visible on the surface, but appears, together with chalcocite, a very few feet below the surface in many pits and short tunnels along the line of the deposit. The richest showing is said to be on the Leonard, where much solid chalcocite appears. Throughout the rest of the zone it occurs only as small grains scattered through the rock. The average grade of the ore here exposed is very difficult to determine without deeper exploration, which is now in progress. The surface appearance fully warrants further prospecting.

UPPER SNAKE RIVER CANYON FROM HUNTINGTON TO MINERAL.

GENERAL FEATURES.

A few miles above the mouth of Burnt River, Snake River enters the canyon, through which it flows practically until its junction with the Columbia. For a few miles north of Burnt River the canyon is rather narrow and about 2,000 feet deep. Above this point it broadens and the divides recede; the slopes are more gentle, while the depth is fully maintained. Along the bottom are several large bars and gravel benches supporting prosperous fruit and hay ranches. The grass-covered slopes are bare of forest until elevations of 4,000 feet are attained.

GEOLOGY.

Until well down toward the mouth of Powder River the canyon is eroded almost entirely in older rocks. A little above Burnt River the basalt flows descend nearly to the level of the river, and a short distance above the mouth of Connor Creek a ridge on the Idaho side is covered from the summit down to the river level by characteristic sloping flows of the Columbia River lava, showing that while the canyon has been reexcavated, the old drainage system was fully as deep as that at present followed by the stream. Another basalt area crosses Burnt River Canyon 8 miles above Huntington; the appearance is very much as if an earlier canyon, draining southwesterly, crossed the present and had been filled to the brim with lava. The Neocene formations west of Huntington are described in a subsequent paragraph on Rye Valley, Mormon Basin, and Malheur.

The older rocks form two well-defined divisions. The lower division consists of greenstones, predominatingly old rhyolites, rhyolite tuffs, and quartz-diorite-porphyry; it occupies the vicinity of Huntington and the narrow canyon extending for 8 miles north of that place. It is probable that this whole series consists of old surface flows. These rocks are covered by an extensive series of clay slates and limestones of uncertain age. Near the contact, on Burnt River and on Snake River, are red and green tuffaceous slates embedded in the greenstones before the main sedimentary series begins. Similar rocks crop near the head of Durbin Creek, giving the whole series a strike of N. 30° to 45° E., and a northwesterly dip, which near the contact is 20° and at the gypsum mine 2,000 feet above Huntington as low as 12° to 15°. The same contact crosses the river and is exposed in the creek leading up to Mineral from Snake River. The strike of the clay slates is here N. 80° E. and the dip is 60° N.

Besides the predominating black clay slates the sedimentary series contain heavy masses of bluish-gray limestone. The largest mass, several hundred feet across, is exposed 4 miles above Huntington, continues up to the top of the mountain between the two rivers, but is not seen in Snake River Canyon. Other heavy limestone masses crop above the Connor Creek mine. At the Gypsum mine crinoid stems and doubtful remains of corals were found. The age of the series is in great doubt; most likely the sediments and old lavas are of Triassic age.

LIME AND GYPSUM.

The largest limestone masses in Oregon, conveniently situated near railroad, are found 4 miles above Huntington, and kilns have been in operation for a long time. It has been known for thirty years that important gypsum deposits occurred near Huntington, but it is very recently that they have been utilized. The deposit is situated 4 miles from Burnt River and 8 miles from Huntington, near the summit of the ridge overlooking Snake River. The elevation at the lower tunnel is 3,950 feet. A tunnel 170 feet long connecting with an upraise 100 feet long exposes a bed of good quality of gypsum, 20 feet thick, resting with gentle westerly dip on slate and limestone and covered by red and green tuffaceous slate. About 80 feet higher up is another stratum of gypsum, 30 to 40 feet thick, and covered by gypsiferous limestone and green volcanic tuff. The conditions for exploitation are excellent. The gypsum is in part pure white and crystalline; in part, however, it contains thin strata and films of greenish chloritic mineral. The Oregon Plaster Company quarried 1,800 tons of rock at this place in 1896 and erected works near the limekiln on Burnt River which the same year were destroyed by fire. A plant for the dressing and milling of the material has been recently rebuilt. In 1899 and 1900 several hundred tons of plaster of paris were produced. Discoveries of gypsum are also reported from the Idaho side and in similar geological position.

MINERAL DEPOSITS NEAR HUNTINGTON.

A few miles above the mouth of Burnt River, on the Oregon side of Snake River, a number of claims are located, among them the Bay

Horse, which stands credited with a small silver production in 1891. Other prospects with some galena and zinc blende are reported from the summit of the ridge separating the rivers. The localities were not visited, but are evidently contained in the basal series of old igneous flows similar to the deposits of Mineral.

SILVER MINES OF MINERAL, IDAHO.

The road to Mineral follows the west side of Snake River for 20 miles below Huntington, where the river is crossed and Dennett Creek ascended for a distance of 4 miles. The lower part of the creek has a southwesterly direction and forks about 3 miles above the river. The town of Mineral is situated on the South Branch, which heads a few miles due east among the gulches leading down from Iron Mountain, the elevation of which is over 5,000 feet. The town and the smelters are situated in the narrow gulch at an elevation of 3,000 feet. As along Snake River, the hillsides are bare, but good forests crown the summit of Iron Mountain.

Fissile clay slates with one intercalated stratum of limestone crop in the gulch below the junction, the strike being N. 80° E. and the dip 60° N. Below the slates follows, apparently conformably, a heavy series of old greenstones and tuffs, together with some minor diorite areas and occasional dikes of basalt.

The mines of Mineral were discovered about twenty-five years ago, but for many years remained undeveloped prospects. About 1888 a wagon road was built into the district, and in 1889 Messrs. Biddle and Lang erected the first smelter. This ran successfully, applying the pyritic process, until 1893, when, owing to the low price of silver, the works were closed down. Another smelter had been built in 1890 just below the forks of the creek, and this also was closed in 1893. Smelting charges were $16 per ton of wet ore, and coke at the smelter was worth $28 per ton. The camp remained dormant until November, 1900, when a new 60-ton smelter was being erected by Mr. A. J. Crook. The total production of the camp is roughly estimated to be 600,000 ounces of silver.

Most of the ore deposits occur in the igneous rocks below the clay slates, in the immediate vicinity of the town. The most prevalent type contains chalcopyrite, pyrite, galena, zinc blende, and tetrahedrite in a calcite gangue. No great depth has been attained, and in some cases surface oxidation prevents accurate diagnosis; but in general the deposits seem to be vein or irregular bodies connected with fissures. To a large extent the ores are certainly formed by replacement of the rock.

The Silver Bell is situated on the hillside, a short distance above the town, at an elevation of 3,600 feet. It is developed by three tunnels and in all by 2,000 feet of drifts and crosscuts. The upper tunnel cuts the vein 100 feet from the portal. The strike of the vein seems to be northwesterly, the dip southwesterly, but the ore body is not very regular or well defined. A short distance beyond the crosscut it widens to a big body, 40 feet square, of oxidized ore, full of copper sulphate and gypsum. A similar big chamber is struck on the middle level. The lowest tunnel is in sulphide ore, less rich than that of the upper workings.

The Silver Bell has been worked, together with the Black Hawk and the Maria, and the group is credited with the largest part of the total output of the camp. Besides copper, the ore contains much silver and a little gold.

The Maria is located on the hillside south of the town, and is developed by several tunnels for a vertical distance of 200 feet. The vein is fairly well defined, from 2 to 4 feet wide, and dips northeasterly. The dip decreases in depth to 20°. A dike of basalt similar to that found in the Jessie cuts the vein. The oxidized ore is confined to within 50 feet of the surface. In depth the sulphide consists of pyrite, chalcopyrite, tetrahedrite, galena, and zinc blende, all fine grained and intimately intergrown with calcite gangue. The percentage of copper is small—from 1 to 2 per cent. The average silver content is said to be 25 to 30 ounces per ton. The zinc blende and galena, which are not very abundant, are most intimately intergrown in concentric masses. A specimen of richer ore assayed contained 0.28 ounce of gold and 55.92 ounces of silver per ton. The production of the Maria is reported as 150,000 ounces silver.

The Black Hawk, situated between the Silver Bell and the Maria, is similar to the latter. It is credited with 200,000 ounces of silver.

There are many other prospects of note in the camp. The Eagan group, northwest of the town, on the steep slope toward the North Fork of Dennett Creek, is credited with 100,000 ounces of silver, found in rich tetrahedrite ore, also containing arsenic. The Boone and the Enterprise, on the ridge north of the town, have also produced some rich ore.

The Jessie, situated half a mile northwest of the town, at an elevation of 3,400 feet, represents a totally different type of deposit, and is developed by a tunnel 100 feet from the croppings. It is contained in a dioritic rock, but in the hanging wall is a dike of normal basalt with diabasic-granular structure. The strike of the well-defined vein is northeasterly, the dip 45° NW. The vein shows 2 to 3 feet of pyrite and chalcopyrite in gangue of quartz and tourmaline; in addition, the microscope shows the presence of specularite, vesuvianite, and a little dolomite and calcite. This ore is said to contain, besides much copper, 0.1 ounce of gold and 3 ounces of silver per ton.

IRON MOUNTAIN.

A large deposit of somewhat titaniferous magnetic iron ore is reported to occur at the head of Dennett Creek, on Iron Mountain. The ore also contains a little malachite from decomposed copper sulphides. The country rock is a diorite. Limestone also occurs in the vicinity, hence it is very possible that the occurrence represents a contact deposit.

PLACER MINES ALONG SNAKE RIVER.

A little placer work has been prosecuted at various places along Snake River, especially between Mineral and the mouth of Powder River. These localities were not visited. Placers have also been worked on Fox Creek and especially on Connor Creek, naturally deriving their gold from the Connor Creek vein. The whole creek has been worked over twice, and every season some washing is done. The grade of the creek is very steep and the gold coarse. The total production is said to be about $100,000.

CONNOR CREEK MINE.[1]

Location.—This mine, well known in the annals of eastern Oregon, is situated on Connor Creek, a small tributary to Snake River. Heading near Lookout Mountain, this small water course, a gulch rather than a creek, follows a southeasterly course for about 6 miles and joins the main river at a point 14 miles north-northeast of Huntington. The grade is steep and its canyon deep and narrow, branching in two forks near the mine, which is located 2½ miles up from the river. The hills near the river are smooth and covered with grass. Above the mine cliffs of limestone appear and scattered bunches of pine. The elevation at the river is nearly 2,000 feet, while at the mine the corrected aneroid reading is 2,950.

History.—The vein was discovered in 1871 by Wood and Edelmann. In 1872 a 5-stamp mill was running on rock carrying $23 per ton in gold. The mine continued to be worked on a smaller scale till 1876, when a 15-stamp mill was erected. Since that time it has been worked almost continuously, though the production has been irregular and at times very small. The present owners, the Connor Creek Mine and Mill Company, bought the mine in 1884 for $60,000. At the present time there is on the property a 35-stamp mill, with plate amalgamation and concentrators, built some fifteen years ago.

Production.—Statements of production for this mine vary greatly. It is estimated by some that the mine has yielded a total of $9,000,000, but this appears to be an exaggeration. Captain Myrick states that only $100,000 was produced previous to 1876, and he believes that the production since then has amounted to only $1,000,000. At any rate, it is not probable that the total has exceeded $2,000,000.

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[1] Much of the information regarding this mine was obtained from Mr. J. H. Pomeroy and Captain Myrick, the present superintendent. I visited the mine in November, 1900, but owing to a combination of circumstances could not enter the workings.

The only Mint reports containing detailed statistics give the following data: In 1882, production for three months amounted to $26,000. Twenty stamps were dropping and 250,000 tons were in sight. The production up to 1889 was $400,000; in 1889 it was $119,000; in 1890, $24,000; in 1891, $13,000. In 1892 nothing was produced. During the last few years the mine has yielded little or nothing, though development work proceeded on a small scale. Recent developments give hope of resumed production. The period of greatest activity falls between 1880 and 1890.

The mine is exceptionally favorably situated for cheap mining and milling, having abundant water supply and timber available and the workings being well above tunnel levels. As early as 1882 it was expected that the expenses for mining and milling would be reduced to $2.50 per ton, and at the present time they ought not to exceed $2 per ton.

Development.—The vein which crops high up on the mountain is developed by the following tunnels:

Name.	Length.
	Feet.
Upper	486
Middle	577
Lower	610
Bulger	1,200
Dry Creek	1,400
Connor Creek	3,700
Total	7,973

The upper tunnel is about 1,000 feet above the Connor Creek level. The latter is a crosscut about 3,000 feet long, with the drifts on the vein aggregating 700 feet. The Dry Creek follows the vein for 1,400 feet and strikes it by means of a short crosscut. This level is the one on which the mill was built, the Connor Creek being about 150 feet lower.

Country rock.—The vein is inclosed in black clay slate with a general north-northeast strike and dip of about 60° WNW. Above the outcrops are heavy bodies of blue limestone, which, however, are not cut by the vein or by any of the drifts or crosscuts.

The vein.—The strike of the vein is N. 40° W., the dip from 70° to 75° SW., thus decidedly crossing the slates in dip and strike. The outcrops are only distinctly visible in one place, though in many places the vein has been stoped almost up to the grass roots. The vein has been followed and stoped on all levels in a westerly direction up to a break locally termed the "final cut-off." This forms a body striking N. 31° E. and dipping from 45° to 60° SE. It consists apparently of a shear zone of puckered, somewhat chloritic clay slate about 130 feet wide and crossing the normal slates in strike and dip. On none of the upper five levels has the vein been traced west of this "final cut-off;" in fact, it is understood that no very extended search has been made for it. The principal ore bodies were found above the Dry Creek tunnel; between this and the lowest level the vein was very much crushed and split. Recently extensive explorations have been made beyond the "final cut-off" on Connor Creek tunnel level. The vein has finally been found here and is similar to that in the old workings, carrying excellent values in coarse gold. This is very encouraging, as it is now believed that a pay shoot may extend all the way up to the surface on the west side of the final cut-off. More explorations are necessary, however, to prove this. In the light of the latest results the cut-off appears as a fault, later than the vein and cutting across it. Beyond the cut-off normal slates are again found.

There are also several minor faults cutting the vein. These have in general a northeast strike and southeast dip, the horizontal throw amounting to 30 to 50 feet to the left, going northwest on the vein. The faulted part soon curves back into the normal line of the vein.

The vein is followed along its whole course by a dike from 6 to 8 inches wide, always on the hanging wall and cutting the slates sharply. In appearance it is a greenish, greatly altered rock containing abundant cubes of pyrite. The slates adjoining the vein are in places well filled with cubes of the same material. The ore consists of normal white, coarse vein quartz up to 8 feet wide and never pinching out entirely. The usual width of the quartz filling is from 3 or 4 feet down to 18 inches. The gold is largely native and often in very coarse masses. The value is from $19 to $20 per ounce. This is unusually high, but similar to that from the Virtue mine. A small amount of pyrite and sometimes argentite accompanies the quartz. When the pyrite occurs in heavy masses its value is low. The quartz is partly massive, partly ribboned by subsequent shearing. On Connor Creek level the recently discovered vein is 18 inches thick, massive on hanging wall, and ribboned on foot.

Pay shoots.—The vein carries the best values when of somewhat considerable thickness, say 3 to 4 feet. It has been stoped from the level of Dry Creek tunnel up to the croppings. The main pay shoot is irregular in outline and attained its greatest development of 1,400 feet in length on the Dry Creek tunnel. It consisted of milling ore worth $3 to $10 in gold per ton. Within this shoot, however, smaller and much richer ore bodies were found carrying coarse gold. One of these pitched 60° NW. on the vein, and its extent was 60 feet by 10 feet, the vein being of average width. The rich ore may be irregularly distributed through the thickness of the vein, or there may be 1 foot of exceptionally fine ore on the hanging or on the foot. The above-mentioned rich shoot contained $120,000, the coarse gold being associated with some argentite.

Secondary alteration.—The vein being located on a steep sidehill, where the watershed is irregular and fluctuating, it may be expected that secondary changes have taken place. But the evidence is not sufficient to indicate the extent of these changes. Possibly the very rich shoots in which argentite occurs may be due to this cause, and very probably some concentration may have occurred in the sheared (ribboned) parts of the vein, which, however, are not exceptionally rich. The specimens show, however, that the larger part of the ore is of primary origin and not due to later enrichment. Except near the surface the quartz is white, and the pyrite occurring in it, unaltered.

SNAKE RIVER PLACERS.

Occurrence.—No detailed examination has been made of the Snake River placers; indeed, if a solution of the several problems involved were desired, such an investigation would require much field work, extended from the source of the river to its junction with the Columbia. For many years mining on a large scale has been attempted, but not until recently has any measure of success been achieved. The gold is extremely fine, flaky, or floury, and occurs in thin and not very persistent pay streaks. This fine gold is contained in the sandy bars all the way down from its headwaters, and its origin has been the source of much speculation. It is thought by some to be derived from the lava beds of central and eastern Idaho; this does not appear very probable. Other prospectors have traced its origin to vast bodies of old conglomerates in northwestern Wyoming; this view seems more plausible. A short article by W. H. Washburn[1] explains the occurrence of the gold better than any statement that has come to my notice. It is in substance as follows:

> The gravel bars of Snake River, in Idaho, Oregon, and Washington, have attracted attention for forty years. Extending for hundreds of miles along this river, from its headwaters to its junction with the Columbia, these bars contain gold to the value of from a fraction of a cent to several dollars per cubic yard. The latter values are found in a very few spots and of limited extent, and when discovered are soon worked out by itinerant prospectors. Twenty years ago these best spots were a favorite resort of miners and prospectors in search of a grubstake, but they have nearly all been long since exhausted, so that the man with a pan and rocker has slim picking these days.
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> The source of the gold can not, of course, be accurately determined. The generally accepted theory is that it is the finer particles from the placer deposits of tributary

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[1] Mining and Scientific Press, December 29, 1900.

streams, its extreme fineness and usually flattened shape permitting it to be transported hundreds of miles along with the sand and gravel. In fact, it travels much faster than the larger sizes of the latter. Some claim that the vast lava beds of southern Idaho (which are said to contain a small amount of gold) have contributed the greater portion of the values. In support of this theory it may be said that, so far as the writer has observed, fine gold is to be found in the streams draining any extensive lava formation in a mining country. Probably it has been derived from both sources.

Our investigations having been made from a point about 20 miles below Huntington, Oreg., to 50 miles above Ontario, these remarks will be mostly confined to what is to be found between these points.

The gravel ranges in size from fine sand to bowlders seldom larger than a man's head. The current has a velocity of from 3 to 5 miles per hour. The gold is very unevenly distributed throughout these bars, being generally found in strata of medium-sized gravel, from a few inches to a few feet thick, usually overlain by from 2 to 10 feet of barren sand or gravel. Below these strata the gravel may also be worthless. Depth does not seem to cause any increase in values; where the bed rock has been reached at a few points on the rim it holds but little gold.

As a typical instance of values, on one claim I found about 18 inches of gravel at water level, from which I rocked from 75 cents to $2.50 per yard. It was overlain by about 8 feet of sand practically barren, the gravel below being afterwards proven to carry but little value. Another claim shows strata of from 2 to 4 feet thick and about 150 feet wide by about 300 feet long, carrying about 50 cents per yard, also overlain by about 6 feet of barren sand, the underlay being barren for at least 6 feet to water level. These figures are given to give a fair idea of the pay streaks in general. There are open bars in places with no overlay, and where the pay streak is of sufficient depth they are generally preferred by those engaged in dredging. There are many pay streaks found some distance from the river, but usually under the conditions as to overlay above described. In some places there are strata of cemented gravel from 1 to 3 feet thick, but generally it is absent.

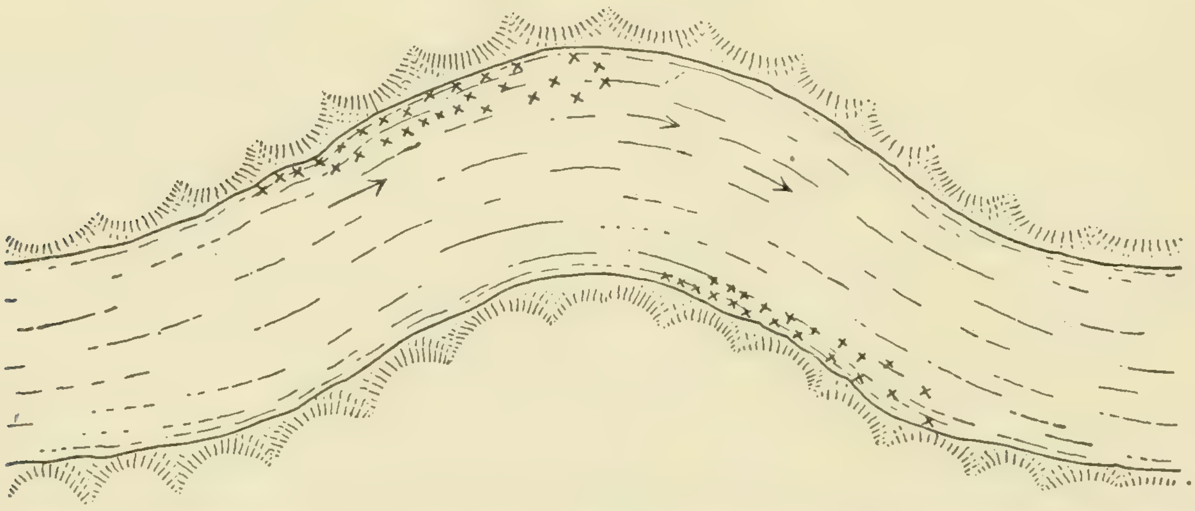

FIG. 87.—Diagram showing manner of accumulation of gold in Snake River bars.

It may be useful to note the conditions under which these pay streaks are laid down, as indicated by the open bars along the river. We find the gold is deposited along the short or inner side of the curves in the course of the river. Any stratum of good gravel in the opposite bank has evidently been laid down at some previous time under the same conditions.

The accompanying sketch (fig. 87) will show the occurrence of gold more clearly. The colors are coarser at the head of the deposit, gradually becoming finer and fewer, and spreading out below, until the gravel is too poor to pay. As long as the river retains its course the pay streak will continue to form as the bar is extended from year to year, thus forming the larger deposits. One old resident worked a certain spot over for eleven consecutive years, a fresh deposit of gold being made by the annual June rise of the river. The average size of the gravel, as well as other signs, seems to indicate that the gold is only deposited where the current has a certain medium velocity. The valley is from 3 to 10 miles wide and quite flat generally, the course of the river having from time to time swerved from side to side across its whole width. At a few points where the bends in the river are made more permanent by rocky banks, the pay streaks seem to be deeper and of greater extent than elsewhere. * * *

The gold above the mouth of the Boise River is very fine, averaging about 1,200 colors to 1 cent, and is worth from $17 to $19 per ounce. Below the mouth of the Boise the gold is not quite so fine, averaging about 900 colors to 1 cent. The value is lower, being from $14 to $16 per ounce. It is always associated with black sand (principally magnetite) and a heavy reddish-gray sand made up of minute rubies [garnets, W. L.] and other various-colored crystals. When carefully separated the black sand contains only a trace of gold. Below Huntington, as far as I prospected, the most of the gold is evidently of local origin, being quite coarse, and nuggets of considerable size are found, although the pure gold from above is still in evidence in favorable spots.

Methods of mining.—The finely distributed gold of Snake River has long been a favorite subject for experiment by people who have "new processes" for catching flour gold. Most of these schemes are based on amalgamation, either on copper plates or by forcing the sand through mercury. Practically all of these have failed. The pan and rocker is occasionally used, but fails, of course, when the gold is very fine and the gravel poor. The ordinary sluice is not a success. The process used with most success is the burlap system. The sluices are made about 20 feet long and much wider than the ordinary box. The bottom is covered by burlap and the screened material allowed to pour over it in a thin, even stream. At intervals the burlaps are taken out and washed. The gold does not always amalgamate easily, but amalgamated copper plates can be used in conjunction with the burlaps as follows:[1]

A short sluice carrying a considerable stream of water is first prepared; attached to this there is an inclined table about 16 feet in width and from 10 to 20 feet in length. Where the table is 20 feet in length it is usually divided in its incline; that is, the first 10 feet adjoining the sluice box is sharper in its incline than the last 10 feet, which is almost level. There are flanges or a rim on each side of this table, 4 to 6 inches high, and through its center it is divided by a partition board, leaving each half 8 feet wide. On the first 8 feet of each length there is placed a quicksilvered copper plate, and over this is laid a sheet of burlap, usually of manila bagging, firmly stretched and secured, so as to give an even surface to meet the current that is to pass over it. To the sluice there are screens attached for catching the coarse gravel and sand, and the gravel being shoveled into the sluice, the fine sand, magnetic iron, and fine gold particles soon reach the burlap sheet that is spread over the table. The current carries forward the sand and all lighter matter, and the short, hair-like surface of the burlap retains the gold and black sand. Some of the gold particles penetrate the bagging and are caught on the quicksilvered plates. After exposure to the current for about twelve hours or less, the water is turned entirely into one side, the burlap sheet on the other side removed and carefully washed in a large vat filled with water, where it is entirely freed of the particles of gold and black sand which adhered to it on the table. It is then replaced on the table, the current turned on again and the burlap on the other side treated in the same way. When the washings of these burlap sheets have accumulated to a considerable quantity in the vat, mercury is poured upon them and, by means of an agitator, the mercury is forced over and over and through the mass of auriferous black sand until it has taken up every particle of gold. The black sand or magnetic iron is then washed out and the amalgam renewed, the free quicksilver separated by forcing through felt or buckskin, and the remainder separated from the gold by fire.

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[1] Mining and Scientific Press, Dec. 29, 1900.

During the last years dredging has been attempted and considerable success has been attained after much experimenting.[1] A suction dredge is in use near Minedoka, pumping the sand and gravel from the river bottom. Ladder and bucket dredges have been lately built on other parts of the river. The pay gravels contain from 5 to 15 cents per cubic yard, the gold being in flat and cup-shaped scales, 1,000 to one cent. In order to make a profit on sand containing 10 cents per cubic yard, at least 1,000 cubic yards must be handled daily. The gravel is screened to one-eighth-inch size, and the gold caught in broad and shallow burlap sluices, with an area of 1,300 square feet.

The cost of dredging by means of suction pumps with a capacity of 2,500 cubic yards per day is stated to be $100 per day, or 4 cents per cubic yard. The ladder dredge is reported to work somewhat cheaper, or at the cost of 3 cents per cubic yard.

LOWER BURNT RIVER VALLEY.

GENERAL FEATURES.

After traversing a deep canyon for 12 miles Burnt River emerges into an open valley near Durkee, turning at the same time to a southeasterly direction, which it maintains until near its junction with the Snake. A few miles below Durkee a canyon again begins and continues down to Huntington with a depth of from 2,000 to 2,500 feet. Above Weatherby a number of smaller tributaries join the river, all heading up toward Lookout Mountain (elevation 6,900 feet), the highest point in the divide between Burnt and Powder rivers and a well-known landmark visible from all directions. The elevation of the river at Durkee is about 2,650 feet, descending to 2,117 at Huntington. The grass-covered slopes rise steeply from the narrow flats along the river, and are forested only along the highest portions of the Lookout Ridge. During the rainy season Burnt River carries a considerable amount of water, but so much is taken out in ditches for mining and agricultural purposes that it is almost dry at times during August and September near Huntington. Dixie Creek, heading some 12 miles westward on Pedro Mountain, is the only tributary of note entering Burnt River from the western side.

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[1] F. Powell, Gold dredging on Snake River: Eng. and Min. Jour., Oct. 6, 1900.

GEOLOGY.

Burnt River Canyon, in the region here described, is cut in older rocks—slates, limestones, and diorites. The great sedimentary series is, as far as can be seen, conformable with the Huntington and Snake River series. It consists almost exclusively of fissile clay slates and strata or lenses of gray limestone. It is only toward Unity and Pleasant Valley that greenstones and greenstone tuffs begin to appear, probably as intercalated flows. The strike is very constantly N. 70° to 80° E., and the dip usually at very steep angles toward the north. The most prominent stratum of limestone crosses Cave Creek south of Burnt River Canyon, and continues with well-marked croppings several hundred feet wide to the foothills of Durkee Valley. The age of this series is not known, no fossils of any kind having been found in the limestone masses or in the slates. Occasionally greenstone-schists are interbedded with the clay slates.

Large masses of granitic rocks are intruded into this sedimentary series on a line from Lookout Mountain to Malheur, a line also followed by the gold deposits. The most easterly of these masses occupies Lookout Mountain and the summit of the ridge. A smaller area of granodiorite begins on Gold Hill, a few miles southeast of Durkee, and probably continues down as far as Sisley Creek. The third and largest area contains quartz-diorite and diorite along the margins, but granodiorite and possibly also granite in the center. This is the area of Pedro Mountain, extending for about 10 miles southwest and northeast, with a maximum breadth of 6 miles. The intrusive character of these rocks is proved by dikes of similar material in the slates and by contact metamorphism of the latter. As far as observed, these granitic rocks show no schistosity.

The Neocene formations are developed extensively only in Durkee Valley and in the foothills 5 or 6 miles north and northeast of the railroad station. Durkee Valley is one of the many peculiar depressions found in the mountain rims surrounding the great Neocene lake basin of Idaho. It is surrounded on all sides by slopes of slates and similar old rocks. The only outlet is a narrow canyon which Burnt River seems to have cut at a comparatively late date, and which is so inconspicuous that from most points of view the valley looks like a closed basin. The entrance of Burnt River from its upper canyon is equally inconspicuous. This valley is filled with a series of fine-grained sediments, well bedded and interstratified with rhyolitic and basaltic tuffs. Near the Gold Hill mine basalt flows are intercalated in the beds and a few miles north of Durkee a butte of igneous rock protrudes through the sediments. The beds rest against the slates on both sides of Burnt River at its entrance in the valley. The elevation of the top beds is 3,100 feet, and they are capped by horizontal strata of calcareous tufa deposited by the abundant springs which here issue from the limestone lenses of the older series. On the northeast side these Neocene beds reach a much higher elevation, probably 3,500 or 4,000 feet. The general structure is that of a shallow syncline, the beds dipping 6° to 10° toward the center of the area. Near the railroad crossing at Unity, cuts expose contorted siliceous beds of the older series separated by an east-west fault from the Neocene tuffaceous sediments, which here dip 13° E. and are cut by several small fissures showing repeated normal faulting of 1 or 2 feet. Neocene conglomerates are also exposed at several points northwest of Durkee. The total thickness of the Neocene sediments and tuff is at least 600 feet.

Small areas of rhyolite are found on the slopes high above the valley. The long ridge a few miles northwest of Lookout Mountain is covered by a series of basalt flows, bedded after the manner of the Columbia River lava.

FIRE OPALS.

A few miles below Durkee a small creek joins the river from the slopes of Lookout Mountain and cuts through the bedded series of tuff. A few hundred feet from the Gold Hill mill opals have been found in this yellowish-gray rhyolite tuff, and a quarry opened to exploit the occurrence. The opals are abundant, filling cavities in the rock, but most of those which were examined had a bluish color and did not possess much fire. A pit 50 feet square and 30 feet deep has been excavated, but the operations are suspended at present. In connection with the opal occurs a peculiar mineral in the form of white fibers, resembling wool. This has recently been examined by Dr. A. S. Eakle,[1] who finds that it is a new zeolite closely related to stilbite.

GOLD-QUARTZ VEINS.

Auriferous veins and placers accompany the series of intrusive granitic rocks from Lookout Mountain to Malheur. In contrast to the strongly developed vein systems of the Sumpter region, these veins are not very persistent. They can not be traced for long distance, nor are directions of strike and dip constant. On the whole, this belt is more noted for its placers than for veins, from which fact it might be inferred that the gold is scattered in many small fissures rather than concentrated in prominent vein systems.

Several prospects are located north of Lookout Mountain, but have not as yet attained prominence. On Chicken Creek, near Weatherby, are several veins which have been worked in a small way for many years. Among these are the Weatherby Bonanza, Gold Thread, and the Essex, none of which were visited.

The Gold Hill mine is located 4 miles southeast of Durkee, at the foot of Gold Hill, a prominent rounded mountain which overlooks Burnt River Canyon. The elevation at the mine is 3,075 feet, while on the summit of the hill 4,050 feet is attained. On the east side of Gold Hill granodiorite with some dikes of finer-grained diorite is the prevailing rock, while the western slope is occupied by slates with a bed of crystalline limestone 100 feet wide. The contact runs in an irregular line over the summit. Croppings of quartz are seen in many places in the granodiorite between the lowest tunnel and the top of the hill. Rich quartz has been taken from many of these. It is clear that the hill is traversed by a network of small veins. The main tunnel is driven for 1,700 feet south-southwest with the intention of reaching the contact. There is, however, little reason for believing that a large vein exists on this contact. In the different tunnels 6 or 8 veins have thus far been found, most of them having an east-west direction and southerly dip. The first vein found is the Spring Gulch, a sharply defined quartz vein 2 feet wide, dipping 20° SE. It contains good, free milling ore, a considerable part of which has been stoped. The quartz contains 2 per cent of sulphurets which are of high value. Adjoining the quartz is altered granodiorite containing much sericite, pyrite, and calcite, though no calcite is contained in the vein. West of the Spring Gulch another vein is opened, showing 4 feet of crushed granodiorite with quartz seams, accompanied by a gradually fading sericitic zone. A few hundred feet from the portal the main tunnel cuts a horizontal quartz vein from 2 to 4 inches wide with the accompanying narrow sericitic zone, which continues for a long distance. Several other veins with east-west strike are cut by the tunnel. One of these, 1,700 feet from the portal, shows 2 to 4 feet of quartz, accompanied by a zone of strong sericitic-carbonatic alteration. Development work is still in progress, though some ore from the Spring Gulch vein has already been extracted and treated in the 10-stamp mill built below the tunnel. The mine is owned by the Burnt River Gold Mining Company and managed by Mr. F. Powning.

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[1] Zeitschr. f. Kryst. und Min., Vol. Vol. XXX, pt. 2, 1898.

The Gold Ridge mine is situated 4 miles south of Durkee, at an elevation of 4,230 feet. It is an old discovery, doubtless found soon after the placers in the creek below it. A 10-stamp mill was built in 1881 and operated until 1886. The mine was then idle until 1896, when work was resumed for a short time. Another period of quiescence followed, until in 1900 an attempt was made to open the vein in depth by means of a vertical shaft 250 feet deep. The veins had not been reached by the crosscut from the bottom of the shaft when the mine was visited. Total developments consist, besides the shaft, of 2,000 feet of tunnels. The total production is given by Mr. H. R. Nichols as $210,000, practically all extracted from 1881 to 1886.

The country rock at the mine is a normal diorite of medium grain, which southward changes into a coarser and more granitic rock. Three principal veins, not far apart, cut this diorite, two of them striking N. 51° W. and dipping 65° SW. A third strikes more nearly east-west and dips south. A few hundred feet to the west, near the shaft house, is a flat blanket vein, upon which, as yet, but little work has been done. The veins, which have inconspicuous croppings, cross the summit of the ridge 200 feet above the shaft. The lowest tunnel is 75 feet below the collar of the shaft. Thus far only the oxidized ore above the tunnel has been worked, and if values continue there would seem to be fair assurance of a new lease of life for the mine. The veins are sharply defined, with normal quartz filling 2 to 3 feet wide. In several places branching veins are met with. The ore above tunnel level had a value of $12 to $15, the largest part of which was free milling, the gold having a value of $18 per ounce. The concentrates were rich, containing 8 ounces of gold and only 1.5 ounces of silver. The pay shoots on the two easterly veins are said to be 780 feet long, while that on the third is considerably shorter.

PLACER DEPOSITS.

A number of gulches in the vicinity of Durkee and Weatherby have been worked in early days, and some are not yet exhausted.

A few miles northeast of Durkee is Parker Basin, with some placer mines; 5 miles southward, below the Gold Ridge mine, are the Raven placers, in Shirttail Creek, which are said to afford promising ground if water could be brought to them. Most celebrated, however, are the diggings of Sisley Creek and Chicken Creek. The former is a tributary of Burnt River entering near Weatherby and heading a short distance south of Lookout Mountain. Rich placers, now mostly worked out, were found at its mouth, and more or less work has been done for a distance of 7 miles, up to Chicken Creek, a tributary joining Sisley Creek from the east. The Chicken Creek placers have been mined for many years, producing from $8,000 to $24,000 annually, and are not yet exhausted. The creek is said to carry pay up to the divide, and even across the latter on the Snake River slope some pay is found.

The gravel bed of Burnt River is more or less auriferous all along from Bridgeport down to the mouth, and the low bars have been worked with some success, both in the upper canyon and below Durkee. The gravels in the river bed itself are also auriferous, but in the upper canyon heavy bowlders interfere with successful work. Between Durkee and the mouth of the lower canyon good dredging ground is said to exist, though the gravels are probably not of high grade. At Weatherby, where the canyon widens to a bottom 700 feet wide, just below the mouth of Sisley Creek, placer work is done by the Pomeroy Dredging Company, of Portland. The area available is about 160 acres. The maximum depth of the gravel is up to 35 feet. Prospecting shafts indicated a yield of from 17 to 25 cents per cubic yard, of fairly coarse gold, most of it contained next to the bed rock. The dredge is of the ladder-and-bucket chain type, 100 feet long and 33 feet wide. The ladder is 76 feet long and carries 35 buckets, each holding 5 cubic feet. Actual capacity is about 1,500 cubic yards per twenty-four hours. After passing through a 15- by 4-foot trommel, which eliminates cobbles over 4 inches in diameter, the gravel passes through a suspended sluice 140 feet long, 3 feet wide, and 2 feet deep, containing wooden riffles shod with sheet iron, and having a grade of 9 inches per 12 feet. The operating necessitates 6 tons of coal a day, at $6 per ton; 10 men are employed, and the total expenses are about $70 per day, or a cost of 5 to 7 cents per cubic yard. The cost of the whole plant, including prospecting operations, was $68,000.

At the mouth of Dixie Creek the gravels of the river bed have also been prospected with a view to dredging, but they are said to be less rich here than above, and the gold is finer in size.

All along Burnt River, from Huntington up to Gold Hill, small bars are found 50 feet above the present bed; all of these have been worked and are practically exhausted. Corresponding to this former stage of the river are gravel terraces, 50 feet high, near Durkee, extending up to the mouth of the upper canyon.

Near Weatherby small gravel bars are also found as high as 200 feet above the river.

RYE VALLEY MINING DISTRICT.

GENERAL FEATURES.

The well-known placers of Rye Valley are situated 6 miles west-southwest of Weatherby, at an elevation of 3,230 feet. The district is drained by Dixie Creek, a tributary of Burnt River. The stream descends from Pedro Mountain in a narrow canyon to a point about 3,000 feet above the town, where it widens into a broad valley. A mile below, at the mouth of the south fork, the bottom lands are half a mile wide, but 2 miles farther down another canyon begins, which continues to Burnt River, with smooth slopes and an average depth of 1,500 feet. A little west of the high slate hills in which the canyon is cut begins a lower plateau (elevation about 4,000 feet), falling off with abrupt edge toward the south fork of Dixie Creek. On the west, above the table-land, rise the higher mountains of the south fork, which connect with Pedro Mountain. The slopes are bare, only supporting a scattered forest growth high up on Pedro Mountain.

GEOLOGY.

The slopes on all sides of Rye Valley consist of a granitic rock, which in part is a granodiorite. It shows in white outcrops on Pedro Mountain, but is elsewhere deeply disintegrated to a sandy soil. Slates and limestones crop in the south fork along the southern contact of the granitic area. As usual, the strike is east-west, the dip 80° N. Similar rocks are also met in the lower canyon of Dixie Creek. To judge from the large amounts of siliceous argillite, greenstone, and greenstone-schists in the creek, these rocks appear abundantly at the head of the stream.

The valley is another of those basins so remarkably common along the margins of the great Neocene lakes of Idaho. The whole trough is filled with Neocene lake beds, above which rests a basalt flow which forms the above-mentioned plateau, breaking off with a sharp bluff toward the valley. There is little doubt that the lake beds continue below the basalt table, and they may well connect with the lake beds exposed southward on the slopes of Willow Creek. Carved in these lake beds is a series of fluviatile terraces of later date. These are the auriferous deposits. Fig. 88 shows the general relations of the deposits. The lake beds are well stratified, and consist of white and gray clays and sandy clays; they contain no tuffs. The whole series dips 13° to 15° W. Contacts with the crumbling granite on the slopes are difficult to establish. On the western side it is located about 250 feet above the creek bed, while on the eastern side it probably reaches fully 300 feet above the same datum plane. The beds thus form a monocline, possibly separated by a fault from the granitic rock on the west side. If not repeated, the series has a thickness of 500 or 600 feet. Leaves and shells are sometimes found in the lake beds. Rarely, gravels are interbedded in the series, and in such case contain a little fine gold.

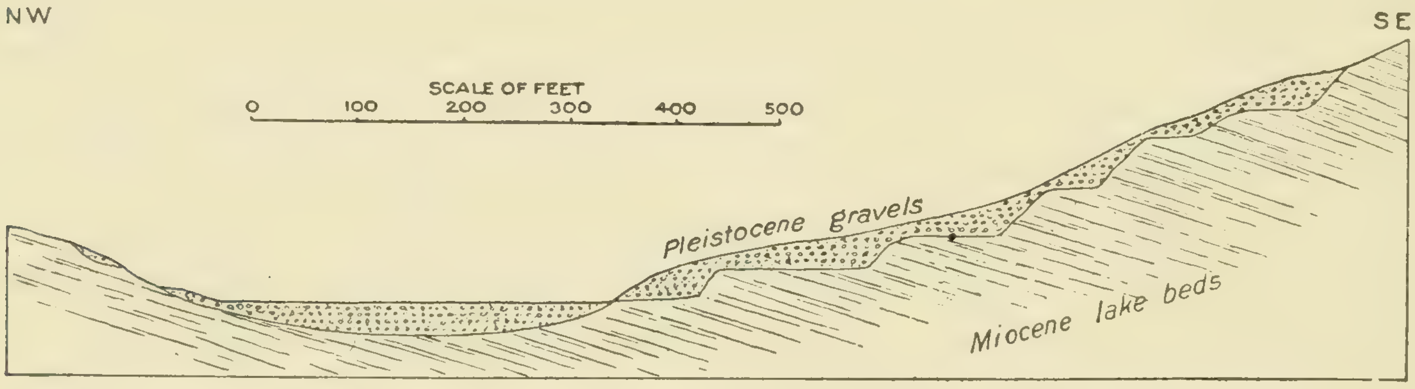

FIG. 88.—Section across Rye Valley, showing relations of gold-bearing gravels to lake beds.

The gravel benches are chiefly developed on the west side of the creek; on the opposite side are only a few insignificant bars. The gravel rests unconformably upon the planed-off surfaces of the lake beds, and forms nearly continuous benches from half a mile above the town to the mouth of the South Fork of Dixie Creek. The width of this gravel bar is from 500 to 900 feet; its maximum elevation above the creek, 250 feet.

The stripping of the gravel has proved the existence of six or eight benches, carved horizontally in the inclined lake beds. The first bench is only a few feet above the level of the tailings; then follows a rise of 30 or 40 feet to the largest bench, which often is several hundred feet wide. Several other benches follow above this. The hydraulic banks are from 30 to 50 feet high. The gravel is coarse and well rolled. A few feet above the lake beds which form the bed rock a stratum of tough clay 4 feet thick is often found, which locally is called "web-foot." In this material the Cartwright Brothers, who own the consolidated placer mines, have found teeth of mammoth and mastodon, which Dr. F. A. Lucas identified as *Mastodon americanus* and *Elephas columbi*, stating that both species are characteristic of the Upper Pliocene.

The creek bed is filled to a depth of about 90 feet with tailings, which vary in width from a few hundred feet to half a mile.

PLACER MINES.

The Rye Valley placers were discovered shortly after 1862, and have been successfully worked up to the present time, with an annual yield of from $5,000 to $50,000, so that the total production is probably above $1,000,000. In 1873 the yield was $50,000; in 1882, $26,880; in 1889 $34,000. During the last few years a steady production has been maintained. Most of the claims have been consolidated and are now owned by Cartwright Brothers. Water is available for only a few months in the year; it is taken from all the gulches of Pedro Mountain, and the quantity varies from 1,500 miner's inches in flood time down to 100 inches in July. The grade of the creek is 3 per cent.

The creek has been mined for 3 miles up from the town, but by far the largest production is derived from the high gravel bars already described. The gold is of a fineness varying from 750 or 800 on the lower bars to 650 on the upper benches. It is fine, the maximum size being that of a pinhead. The largest amount is on the bed rock, though some fine gold is distributed throughout. The yield varies from 11 to 30 cents per cubic yard. Some bench gravel still remains, though the supply is by no means inexhaustible.

It has been proposed to work the gravels in the stream bed by bedrock flume or by dredges. Both projects offer some difficulties, as the depth is 90 feet. Borings in the creek bed are said to show an average content of 30 cents per cubic yard.

QUARTZ MINES.

A number of quartz veins containing silver have been found on Pedro Mountain and attracted great attention between 1870 and 1880. The Monumental, Green Discovery, Washington, and Rising Sun veins were known in 1872; all of these were very rich in wire silver, chloride, and silver glance, besides containing a little gold. In 1875 a 5-stamp mill was erected on the Lafayette, a gold-silver vein, and a similar pan-amalgamation plant on the Green Discovery. In 1880 the New England and Oregon Mining Company erected a large pan-amalgamation mill, spending $50,000 on the property, evidently with unfavorable results. All these veins are situated high up on Pedro Mountain. Green Discovery is said to strike northwest and dip 70° SW.

In the canyon of the south fork, leading up to Mormon Basin, are many quartz prospects containing both silver and gold; tetrahedrite is frequently found in them. Seven miles from Rye Valley a 3-stamp mill had been erected, but was idle in 1900. It was built to treat the oxidized sugary quartz of the Golden Gate, a small, flat vein occurring in granite half a mile north of the road. The contact between granite and metamorphic schist with crystalline limestone is crossed a short distance from the wagon road.

MORMON BASIN, MALHEUR AND CLARKS CREEK DISTRICTS.

GENERAL FEATURES.

Willow Creek is one of the larger tributaries of Snake River, and joins it a short distance above Huntington. West of Rye Valley Willow Creek approaches Burnt River, both flowing in an easterly direction. A bare, comparatively gentle ridge separates the two rivers, its divide rising from 1,000 to 2,000 feet above the streams. On the slopes of this ridge, from 6 to 12 miles west of Rye Valley, are situated a number of famous placer mining camps—Clarks Creek and Bridgeport on the Burnt River side; Mormon Basin, Amelia, Malheur, and Eldorado on the Willow Creek side. But a short visit was made to these localities, and the observations lack much in detail.

GEOLOGY.

The broad ridge separating Willow Creek and Burnt River consists chiefly of pre-Neocene rocks. The granitic area of Pedro Mountain ends just east of Mormon Basin, but a smaller separate area projects to Amelia between Mormon Basin and Malheur. The rest of the ridge is made up of clay slates, siliceous slates, and some greenstone schists. The general strike is west-southwest, the dip steep northwest, sometimes changing to south-southeast. The series is clearly the continuation of that exposed near Weatherby and Connor Creek.

The Neocene volcanic rocks are not very abundant. In Clarks Creek, near Griffin's ranch, rhyolite begins and connects with the great rhyolite area north of Bridgeport. Associated with it are bedded tuffs, which continue, skirting the foothills, toward Bridgeport. Small basalt flows crown the hills north of Mormon Basin, and near Willow Creek thin basalt flows overlie lake beds. A dike 75 feet wide of normal basalt, with diabasic granular structure, cuts the granodiorite of Pedro Mountain on the road from Rye Valley to Mormon Basin, 7 miles from the former camp.

South of Bridgeport a series of gravel benches, at elevations of from

3,650 to 3,700 feet, begins, and skirts the hills eastward as far as the south side of Clarks Creek. The gravels, which are from 10 to 20 feet thick and highly auriferous, rest on soft tuffaceous lake beds, which again lean against slates and schists. The whole indicates a period of quiescent water during the time of the eruption, followed by an epoch of fluviatile activity at a time when Burnt River stood 250 feet higher than at present.

Similar conditions prevail on the Willow Creek side. The base of the slate hills has an elevation of about 3,900 feet, and the shallow gulches cut in the slate above the base are filled with 10 to 30 feet of auriferous detritus. A gentle slope covered with subangular wash descends to an elevation of 3,400 feet. In the sharply cut little canyons one-half mile from Willow Creek 50 to 100 feet of white clayey and sandy beds, having the appearance of lake beds, underlie the wash. Near the bottom of Willow Creek fissile clay slate appears below the lake beds. Thin flows of basalt cover the lake beds along Willow Creek. These facts indicate that a body of comparatively still water occupied the Willow Creek Valley at least to an elevation of about 3,400 feet. From a point near the junction of Mormon Gulch and Willow Creek the road continues 20 miles due east to Huntington. Over the whole distance the ridges slope gently southward, and are cut by shallow, broad gulches. Fine-grained deposits, loam and sand, such as elsewhere in Idaho and Oregon are characteristic of lake beds, cover these ridges, and the thin basalt flows occasionally appearing are probably interstratified with the sediments. The high slate hills are in view a short distance northward. Along the road the highest point reached is 4,100 feet above the sea. All this would seem to indicate that, besides the level mentioned at an elevation of 3,400 feet, there might be present an older and higher level of deposition having an elevation of over 4,000 feet, both indicating Neocene lake levels, the former corresponding to the Pliocene Idaho lake, the latter to the Miocene Payette lake.

PLACER MINES.

All of the districts included in this description have yielded heavily in placer gold, but the production has diminished greatly and gradually. Except Clarks Creek and Bridgeport, the camps are situated in Malheur County, and constitute its only producing area. The total production is impossible to obtain with even approximate accuracy, as the records are very defective. The earlier returns from Malheur County are probably under those of Baker County. The available reports give the production of Malheur as $60,000 in 1889, $40,000 in 1890, $29,000 in 1893, $13,000 in 1894, and $11,600 in 1899.

Mormon Basin.—The road from Rye Valley ascends the South Fork of Dixie Creek, reaching its divide of schists and greenstones at an elevation of 5,000 feet. From the broad, bare ridge a fine view across Mormon Basin is obtained. Like so many other camps around the confines of the Neocene lake of Idaho, it is a broad, shallow basin 9 miles in circumference. The only outlet is through a narrow canyon at the southern end of the depression. The sloping floor of the nearly circular valley is covered by heaps of tailings from placer mines.

The shallow auriferous gravels rest on fine-grained deposits which look like lake beds. The gold is coarse and has a fineness of about 800. In 1866 a nugget worth $640 was found. Placer mining has been carried on in Mormon Basin since 1863. The water supply is scant, and hence the placers have lasted a long time and are not as yet exhausted. Regarding the yield in early days, but little reliable information is available. In 1882 two American and one Chinese company were operating, with a total yield of $40,000. In 1883 a yield of $35,200 was reported. Since that time the production has greatly diminished.

A number of quartz veins have been known for many years in Mormon Basin. As early as 1863 some very fine specimens of crystallized gold in quartz were found, and in 1873 quartz was worked on a small scale. At the present time Mr. Porter Colt has erected a small Crawford mill, and a little ore is occasionally extracted and milled. The veins seem to be small and of a pockety character.

Clarks Creek.—Going north from Mormon Basin, the Clarks Creek divide, covered with a small basalt flow, has an elevation of 5,560 feet. Immediately below the divide indications of old placer mines appear in Clarks Creek, and gold-bearing gravels continue nearly to its mouth. The most important deposits form benches overlying tuffs and lake beds from Griffin's ranch down. The gravels are from 10 to 20 feet thick, and in many places are overlain by 1 or 2 feet of a white deposit very similar to the kaolin of Pine and Salmon creeks, in the Elkhorn Range (pp. 646, 649). They have been extensively worked and proved very rich, but are now largely exhausted. A yield of $10,000 is reported for 1889, $8,000 for 1890, and $13,700 for 1892.

Malheur and Eldorado.—From Bridgeport south to Malheur, fine gravels are met with in the shallow gulches soon after crossing the divide. Three hundred feet below the summit are the ruins of Eldorado Camp, once a flourishing town. All the way from here to Malheur the gulches have been filled with 6 to 30 feet of gravels of fine texture, which now are almost entirely exhausted. The principal water course is called Shasta Creek, and another gulch just west of it is Rich Gulch. These were the largest producers.

The mining of these gulch gravels has been made possible only by the completion of the Eldorado ditch, 134 miles long and having a capacity of 2,400 miner's inches. Projected in early days, it was completed in 1874 at an expense of $250,000. It takes the water from upper Burnt River and carries it through Shasta Gap across to the

Willow Creek side of the ridge. Shortly after its completion the district attained its greatest production. In 1875 the production is reported as $150,000, and this very likely was the maximum.

At the present time the gulch gravels are practically exhausted, but a hydraulic elevator has been erected on Shasta Creek, near Willow Creek, and it is believed that some of the deeper gravels can be worked at a profit.

QUARTZ MINES.

A number of quartz veins have been found near Malheur, but as yet none of them have attained prominence. The veins strike northeast and contain white quartz with coarse gold. The Red, White and Blue vein is located close by Malheur and is developed by a shaft 150 feet deep. The vein, which is from 1 to 2 feet wide, dips 45° SE., and is contained in clay slates with dioritic dikes. The Golden Eagle is situated near Willow Creek and has been developed by a short crosscut tunnel.

SUTTON CREEK BASIN AND THE BURNT RIVER DIVIDE SOUTH OF BAKER CITY.

GENERAL FEATURES.

A mile south of Baker City, Powder River and Sutton Creek emerge from the deep and short canyons cutting through the volcanic ridge which here bridges the gap between the Virtue Hills and the southern part of the Elkhorn Range. South of these short canyons extends a wide basin, bordered on the south by the Burnt River divide, on the west by the Elkhorn Range, and on the east by the lower hills south of the Virtue mine. The western part of the basin is drained by Powder River, flowing through a deep canyon near its great bend, but opening again into an alluvial valley in the center of the basin. The eastern part is drained by Sutton Creek, with its numerous and spreading branches. A pass with an elevation of 4,000 feet is the lowest gap on the south from this basin into the Burnt River drainage, and this is the direction followed by the railroad, which ascends Sutton Creek to its head, and then, in a sharper slope, descends Alder Creek to Burnt River. The central and eastern part of the basin is formed by rolling hills destitute of forest growth, but the Burnt River divide on the south, as well as the Elkhorn Mountains on the west, is covered by heavier forests.

GEOLOGY.

The geological features of this basin are exceptionally interesting, especially in their physiographic aspect. A key is here found to the direction of the rivers and the stand of the lake levels during Neocene times.

The older rocks belong to the series of argillites with a general east-west strike, which is so prevalent in this part of the Blue Mountains and which has been described in greater detail under the headings of the "Virtue mining district" and the "Elkhorn Range." The hills at the head of the different forks of Sutton Creek consist of black argillites, as a rule with well-defined indications of stratification. Greenstones are often interbedded in the series, and though more greatly altered were probably originally fragmentary volcanic rocks. Isolated masses of limestone occur in the series, as, for instance, in the foothills 1 mile northeast of Norton station. Another area of similar rocks occurs on the Burnt River divide, toward the head of Denny Creek and Stices Gulch on the north side, and Cow Creek and Pine Creek on the south side. Again argillites appear, as already described, in the foothills of the Elkhorn Range southwest of Baker City.

The prevailing rocks of this region are not the older series, but the Neocene volcanic flows. The broad ridge which forms the boundary of the southern side of the basin and the divide toward Burnt River is almost entirely built up of heavy masses of rhyolite. This area has already been mentioned under the heading "Burnt River district." Along the northern slopes of this rhyolite dome rest later eruptions, chiefly normal basalts, in which the canyon at the bend of Powder River has been eroded. The same flows skirt the southern end of the Elkhorn Range and continue northward, forming the whole of the complex of hills which bridge the distance between the Elkhorn Range and the hills of the Virtue mining district. Standing at a commanding point in the basin, one may clearly see that the basalt flows must once have filled the whole western portion of the basin up to a level of about 4,700 feet. These rocks form a series of flows, black or brown in color and with a general and well-defined dip toward the east or northeast of from 4° to 12°. Though varying much in aspect, some flows being extremely vesicular and others conspicuously massive, the rocks all appear to be normal basalts. At the base of the flows in Sutton Creek and Griffin Creek, as well as in the foothills due east of Baker City, rhyolite tuffs are found. These form an excellent building stone, being soft and yet durable, and are extensively used for that purpose in Baker City.

In the eastern part of the basin the volcanic rocks are not extensively developed, but instead the argillites are covered by thin well-washed gravels and soft, light-colored, and well-stratified sediments. More recent subangular wash, carried down by the present gulches, rests near the mountains, on top of these sediments. About 9 miles south of Baker City, in the south-central part of the basin, heavier masses, of medium-sized, well-washed gravel, form the long ridges descending from the Burnt River divide. At the low pass where the railroad crosses into the Burnt River drainage the fine-grained sediments, which appear like lake beds, are strongly developed and occupy the very summit. The most satisfactory exposures are seen in cuts along the railroads, where 20 to 30 feet of these beds are exposed. The dip is here 12° to the east, while in other cuts 2 miles farther toward Baker City similar dips of 30° were observed. The rocks are fine-grained sands or clays, in part distinctly tuffaceous. The field relations show that the beds were deposited very shortly after the volcanic eruptions, and, further, that they have suffered a notable deformation since their deposition. Standing at the prominent point near the gap, an old level of deposition is clearly perceived, the sediments of which skirt the hills on both sides up to an elevation of about 4,300 feet, or 200 feet above the lowest point.

To the Pleistocene period doubtless belongs that epoch of erosion during which the present canyons and valleys of Sutton Creek and Powder River have been cut. To the most recent Pleistocene belong the sediments accumulated along both of these streams, and especially prominent among these is the alluvial valley extending along Powder River for a distance of 3 miles south of the last canyon which Powder River has to traverse before reaching Baker City.

Though the geological facts are not complicated, yet it is by no means easy to interpret the geological history which they involve. The topography, before the volcanic flows, was materially different from that of the present time. Its detailed character can not be ascertained without further investigation, but the fact that the rhyolitic and basaltic flows, for a long distance, descend to the level of Powder River and Burnt River indicates distinctly that a deep depression once existed south of the Powder River bend. After the rhyolite eruptions had built up the high divide between the two rivers extensive outflows of basalt took place, which again radically changed the condition of affairs. Flooding the basin to a height of 4,700 feet along the foot of the Burnt River divide and the Elkhorn Range, these flows also extended northward, and there can be no reason to doubt that they once continued in an unbroken ridge south of Baker City from the Elkhorn Range to the Virtue Hills and that the elevation of this barrier reached 4,200 feet. This, however, is higher than the Burnt River gap crossed by the railroad, and it seems that a necessary consequence of this should have been the establishment of a new course for Powder River through this gap and down into Burnt River Valley. That this did not occur can be explained only on the supposition that the great Neocene lake of Snake River Valley once extended up to and above the level of this gap—that is, to about 4,200 feet. This, indeed, is the highest elevation reached by this sheet of water, as proved by many observations in Idaho. If the lake did extend to this level, a very slight further elevation would be sufficient to establish a northerly outlet for Powder River across the basalt flows south of Baker City. A fairly rapid recession of the level of the lake would very soon have carried it below the Burnt River gap, thus preventing the establishment of a permanent outlet in that direction. This interpretation, though not free from objections, is the only plausible one which can at present be advanced to account for the observed facts.

PLACER DEPOSITS AND QUARTZ VEINS.

Both placers and quartz veins occur in the eastern and western margins of the basin, and have already been described under the headings "Virtue district" and "Elkhorn Range." The only other placers where auriferous gravels have been found are in several creeks on the Burnt River divide about 12 to 18 miles southwest of Baker City. Areas of argillite and other older rocks occur on the Burnt River divide in this vicinity outcropping below the lavas, and placers have been worked in several creeks on a small scale during a long period. Among these creeks may be mentioned Denny Creek and Stices Gulch, on the north side of the ridge, and Cow Creek and Pine Creek, on the south side, toward Burnt River. Placer work is still occasionally prosecuted here. On Pine Creek especially placers were in operation during 1900.

Though quartz veins are said to occur on all of the creeks mentioned, no paying deposits of this kind have thus far been developed.

THE ORE DEPOSITS OF MONTE CRISTO, WASHINGTON

BY

JOSIAH EDWARD SPURR

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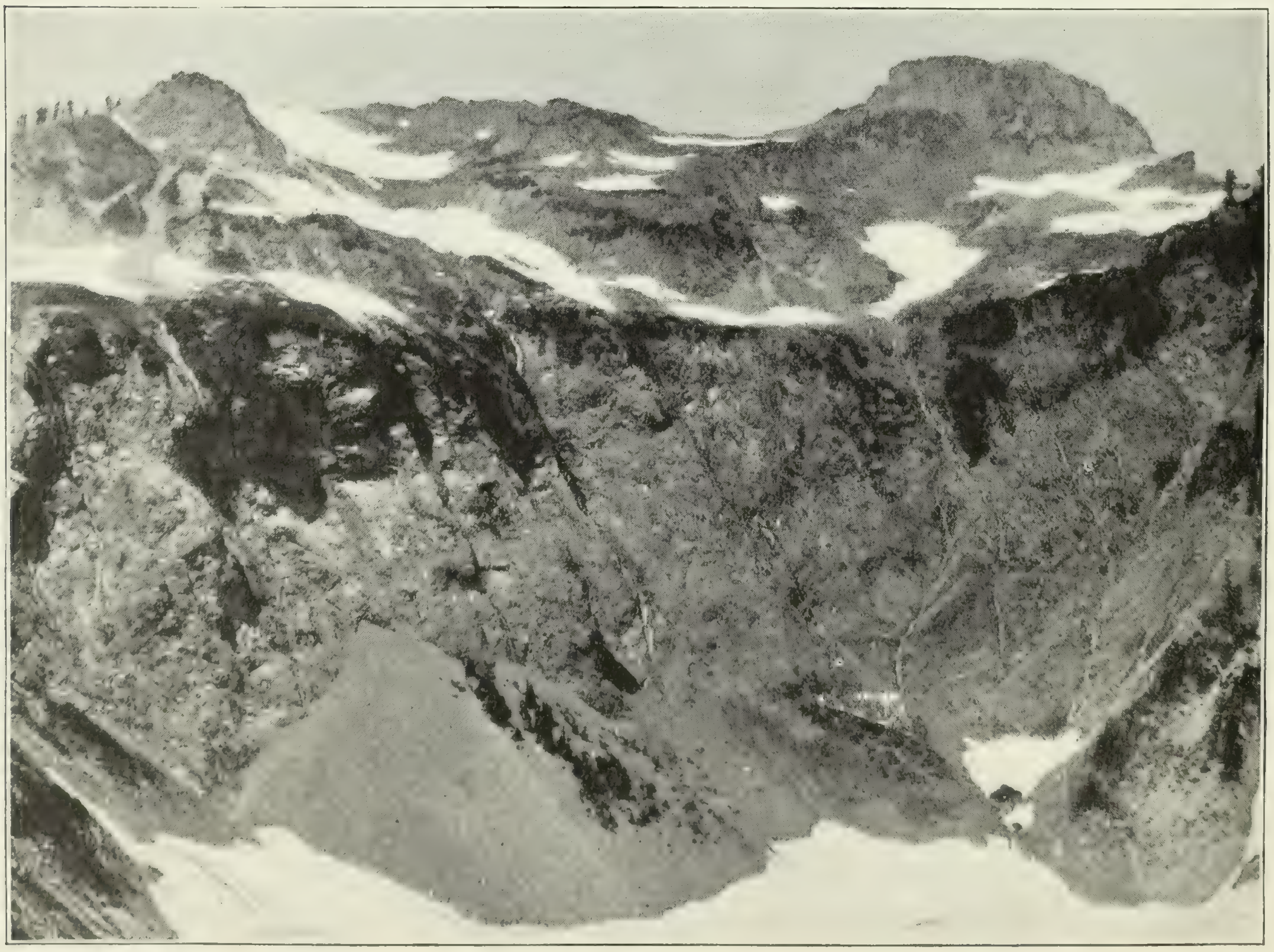
A. MONTE CRISTO AND WILMAN PEAK.



B. WALL OF SILVER LAKE, SHOWING PREDOMINANT JOINTING.

THE ORE DEPOSITS OF MONTE CRISTO, WASHINGTON.

By J. E. Spurr.

INTRODUCTION.

In the summer of 1900 the writer visited Monte Cristo for the purpose of making an examination of the mineral deposits. Only about one month was available for field work. It was therefore planned to confine detailed study entirely to those questions the solution of which would probably be of the most practical value in locating and exploiting mines. Although none of the fields of investigation were covered in all their details, the writer believes that he has collected some significant facts concerning the ores.

The general geology of the region is complicated, and only so much of it has been investigated as is necessary for the understanding of the economic problems. These economic problems do not seem likely, on the first examination of the district, to admit of a solution which will be of interest to the public. The veins are generally easily followed, regular in strike and dip, and rarely broken by subsequent movements. Therefore the problems are not structural. The most important questions that remain are why the ore deposits are richer in some localities than in others, and where the richer deposits may be expected. The answers to these questions, even if they were discouraging in certain localities, would be of great practical advantage in the end, for they would properly direct investments and prevent unwise expenditures. Now, these questions can be answered only by examining the history and conditions of the ore deposition, so that what might appear at first sight to be a technical essay is really the most direct method for reaching practical results.

The mining camp of Monte Cristo is situated in the heart of the Cascade Range, but on its western slope. It lies nearly due east of the city of Everett and about 40 miles distant. It can be comfortably reached only by the Everett and Monte Cristo Railroad, which starts at Everett and terminates at Monte Cristo. Somewhat strangely, there is not even a good wagon road by which the camp may be attained. Aside from the railroad, only trails connect it with other parts of the country. Of these trails the chief is one which runs southward, over Poodle Dog Pass, down Silver Creek, and through Galena, to Index, on the Great Northern Railway. The distance by trail from Monte Cristo to Index is said to be 18 miles.

The journey by rail from Everett to Monte Cristo is a tedious one, requiring from twelve to twenty-four hours. Therefore one has

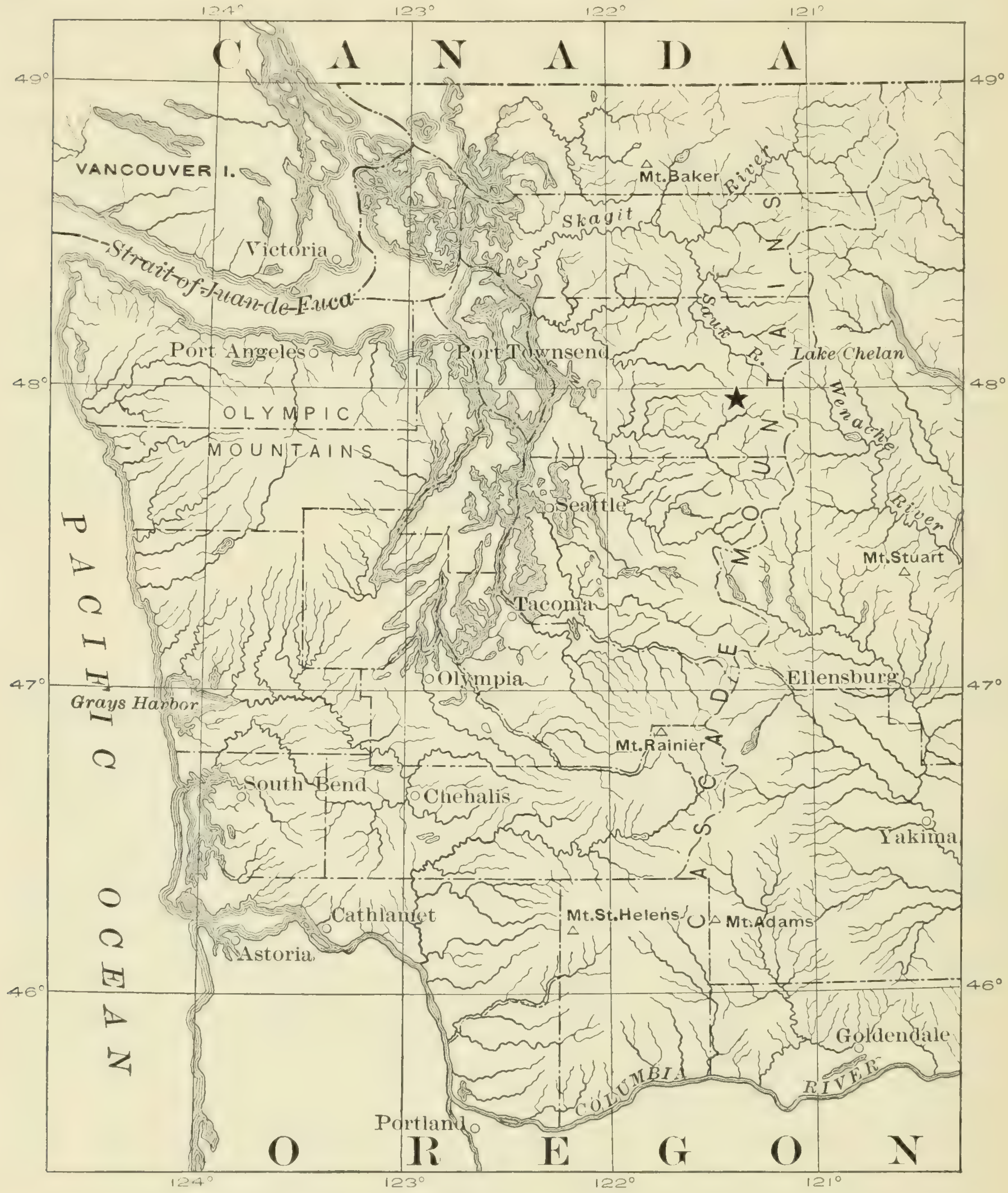


FIG. 89.—Map showing position of Monte Cristo district. The black star indicates the location.

abundant opportunity to study the country. Starting from Everett, the road runs for some time over the drift-covered, fairly level plateau which borders Puget Sound; then it seeks the valley of the Stilaguamish and follows this valley up into the mountains. The route is very picturesque, often running through canyons where the stream is a foaming torrent. A few miles northeast of Monte Cristo the road crosses an almost imperceptible valley divide and enters the valley of the headwaters of the Sauk. At these headquarters Monte Cristo is situated, in a valley basin, with tributary gulches heading in the high mountains.

Although the scenery below Monte Cristo is beautiful, here for the first time one meets the typical rugged topographic features of the heart of the Cascades. The valleys are narrow and deep, the slopes of the mountains so steep as often to appear inaccessible, and the higher mountains contain fields of perpetual snow and small glaciers. Just above Monte Cristo the Sauk Valley divides into two chief gulches, Seventy-six and Glacier. A few miles below the camp another important gulch, that of Weeden Creek, comes in from the south.

Throughout the whole general region in which Monte Cristo is situated many mining prospects have been found. Coming by rail from Everett, one sees prospects and mines along much of the way through the mountains, especially at Silverton. To the south of Monte Cristo there are mining claims nearly all the way to Index. One such is the old mining camp of Mineral City, a few miles from Monte Cristo; and farther south is the mining camp of Galena. At Index there are said to be promising mines. Mines have also been exploited on Troublesome Creek, which lies south of Twin Lakes. North of Monte Cristo, on the opposite side of the high mountain ridge which lies north of Glacier Creek, is the Goat Lake mining district, connected by almost continuous mineralization with that at Monte Cristo. The Goat Lake mines are only about a mile northeast of Monte Cristo in an air line, but by the ordinary trail several times as far. In the region surrounding Monte Cristo there has been hardly any actual mining except in Monte Cristo itself, the region being on the whole in the developmental stage.

The chief mines of the Monte Cristo district are the Pride and Mystery, both operated by a single company. These have extensive workings and a concentrating plant. The ores are shipped by the railroad, which the company has built chiefly for this purpose, to a smelter which has been established at Everett. Preparations have been made at Everett to save the arsenic in these ores in addition to the values already obtained. The Golden Cord mine is probably situated on the same general vein as those just mentioned, and is said to have afforded some good ore. The O. and B. mine is also regarded as a very favorable property. It has been worked and has shipped some ore. There are numerous other prospects in the district of greater or less promise.

The Mystery and Pride mines, with many other claims, were purchased some years ago by capitalists, who built the railroad and erected the smelter to treat the ores. This has led to much active prospecting in the immediate region. The prosperity of the district has been interrupted by repeated washouts of the railroad, causing the shutting down of the mines for long periods. In 1900 the railroad was rebuilt on a much more solid plan and the camp was revived.

The writer desires to express thanks to all those connected with the mines at Monte Cristo for kindly treatment and full and free information. He desires especially to thank Mr. William E. Sutton, the superintendent of the Mystery and Pride mines, for hearty cooperation.

ROCK DIVISIONS.

The following are the main rock divisions recognized in the Monte Cristo district:

1. Ancient granitic rock, not exposed	Mesozoic.
2. Arkoses and comglomerates with some quartzites	Eocene.
3. Earlier andesites and tuffs	Miocene.
4. Tonalite (dacite)	
5. Rhyolite	
6. Balsaltic rocks	
7. Pyroxene-hornblende-andesites, tuffs, and volcanic breccias	Late Pliocene–Pleistocene.

ANCIENT GRANITIC ROCK.

The oldest rock that has been recognized in the Monte Cristo district has not been actually found in place, but is represented by abundant sedimentary deposits which have been derived from it. These deposits are granitic arkoses and conglomerates, containing pebbles and bowlders of granite. In places the bowlders in the conglomerates reach a foot or more in diameter. So coarse a sediment must have been formed near shore; therefore this ancient granitic rock undoubtedly underlies the other rocks of the Monte Cristo district, even if it is not exposed. It is possible, however, that it is exposed in places, but has not been separated from the later granular rock, tonalite.

Correlation.—Not far south from the Monto Cristo area a granitic rock corresponding to this outcrops over large areas. Professor Russell[1] describes the Mount Stuart granite as a light-colored hornblende-biotite-granite underlying Tertiary sandstones, to which it has yielded clastic material. These sandstones correspond to those which overlie the granite at Monte Cristo and which form the lowest series actually recognized here. Mr. George Otis Smith[2] has also recognized in the hypothetical fundamental granite of the Monte Cristo district the equivalent of the Mount Stuart granodiorite, as he has determined the rock to be.

Age.—Since this granite forms the foundation for Eocene arkoses in the region south of Monte Cristo, it is probably pre-Eocene in age. It may provisionally be classed, following Mr. Smith, as Mesozoic.

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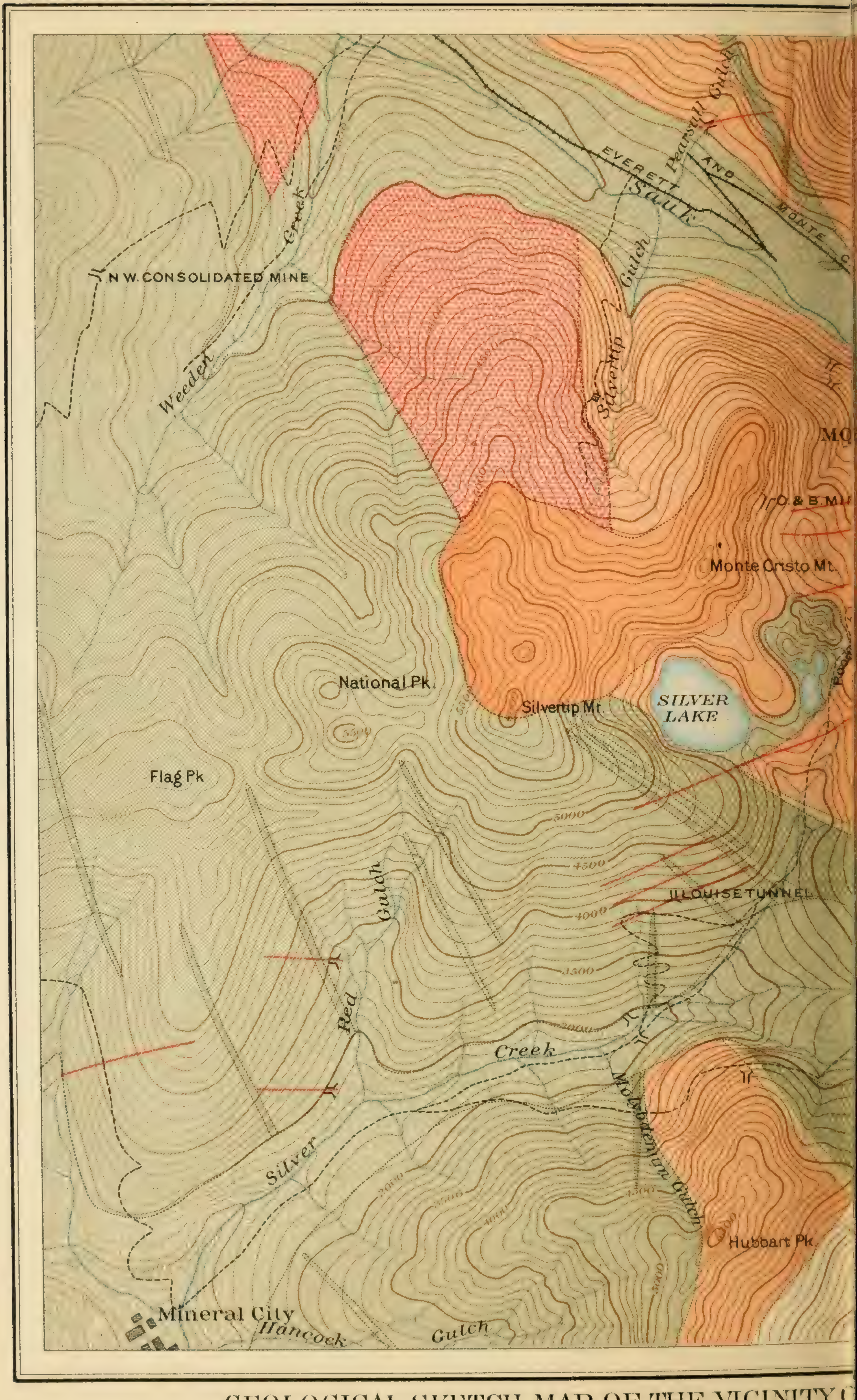
[1] Twentieth Ann. Rept. U. S. Geol. Survey, Part II, 1900, p. 105.

[2] Oral communication.



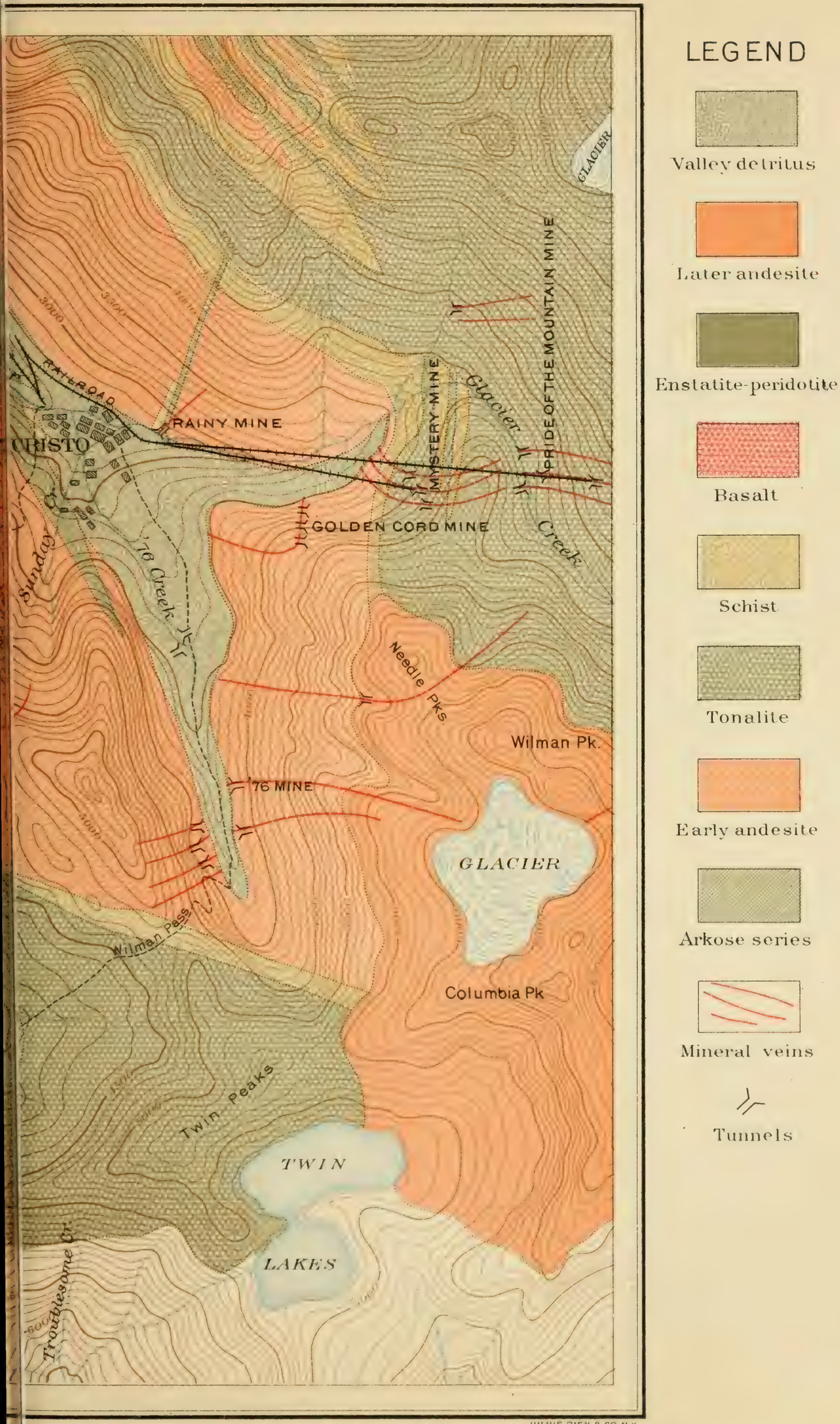
GEOLOGICAL SKETCH MAP OF THE VICINITY

BY J. E. SPURR

Scale

2500 0 25

Contour interval 100 fe



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ARKOSE SERIES.

General description.—One of the most important rock formations in the Monte Cristo region is a series, several thousand feet thick, of granitic arkoses with some conglomerates, less abundant quartzites and shales, and comparatively rare limestones. This series is exposed on Silver Creek and its tributaries and on Weeden Creek. On Silver Creek the arkoses are often distinguishable with difficulty from the parent granite from which they have been derived. In Jumbo Gulch there is a heavy conglomerate containing bowlders of granite up to a foot or more in diameter. On Weeden Creek the rock is slightly different in constitution, containing a larger quantity of nearly black, fine, quartzitic arkoses, which often resemble limestones. Some of the layers are highly carbonaceous, and lignite has been reported from the hills west of the creek. On Silver Creek below Mineral City, in what is probably this same series, impure coal has been reported by Messrs. Willis and Smith.

Crystallinic metamorphism.—With this term, following Dana,[1] the writer characterizes certain alterations in the granitic arkoses, consisting chiefly in the crystalline growth of detrital grains, joined, probably, with the development of some fresh minerals from the decomposition products. This alteration does not appear to be determined by proximity to intrusive dikes, and therefore might be classed as regional metamorphism. Nevertheless, it is found only locally, though what determines this localization was not ascertained. It may, perhaps, have depended upon the original relative composition of the arkoses.

Where this metamorphism has operated, the arkoses, always somewhat granitic in appearance, often come to resemble almost exactly a fine-grained granitic rock. Frequently, however, rounded pebbles of quartzite are found in these rocks, proving their sedimentary origin. When examined microscopically, the texture and general structure of the rock show clearly its relation to the arkoses rather than to the granites. But when the rocks are studied entirely by themselves their structure and composition are such that they might be classed without error as granitic rocks. A fine-grained rock collected at the head of the West Fork of Silver Creek was composed of quartz, striated and unstriated feldspar, and biotite inclosing magnetite. With a low power the distribution of the abundant grains and the difference in texture in different parts of the slide make its original fragmental nature evident, since these characteristics are like those of less metamorphosed or unmetamorphosed arkoses. Under a high power, however, the rock resembles a very fine-grained granitic rock. The biotite is abundant, is fresh, and has plainly formed in place. Small striated feldspars are also fresh, and their crystalline outlines show them to be secondary. Quartz, feldspar, and biotite crystals have grown until they interlock, forming an allotriomorphic granular structure. There is no trace of schistosity. It is probable that the original quartzes have grown by enlargement, while the feldspars and biotites have been regenerated.

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[1] Manual of Geology, 4th ed., p. 316.

The whole series is highly folded, but on account of the massiveness of the beds the attitude is not always easily determinable. On the west side of Weeden Creek, however, the rocks were found to strike N. 5° W. and to dip W. 65°.

Composition.—These sedimentaries grade in texture from a fine slate up to a coarse conglomerate. In general, the grain is medium coarse. When studied under the microscope the rocks are found to be made up chiefly of detrital grains of quartz and feldspar, with occasional bleached biotite. They also contain detrital grains and pebbles of chert, dense volcanic rock (andesite?), and quartzite, often slightly schistose. Widespread secondary minerals, evidently developed after deposition, are chlorite, sericite, and sometimes epidote.

The composition denotes that the sediments were probably derived chiefly from a granitic rock (similar to the Mount Stuart granodiorite) and to a less extent from quartzite and old volcanic rocks.

At the same place as the specimen above described, and close by it, similar fine metamorphic granitic rock forms the matrix of a conglomerate containing .pebbles and quartzite. Under the microscope the nature of these pebbles is plain, the only alteration being that their boundaries have become indistinct. The matrix of the rock, however, is like that just described, having all the structure and composition of a fine-grained granite. The derivation of the biotite is shown in some of the less metamorphosed rocks, where it is seen to form from muscovite, which in a fibrous form results from the decomposition of some of the original minerals.

Relative age of the Monte Cristo arkoses.—The arkose series contains earlier granite, slate, and old volcanics, and is therefore younger than these. On the other hand, it is cut by dikes of andesite, basalt, and tonalite, which are therefore more recent.

On the west side of Weeden Creek the attitude of the arkose series makes it apparently overlie the volcanic series, consisting of andesites, basalts, etc., which lies to the northeast; but since the basalts which lie next to the arkoses seem to be intrusive into them, the apparent relation indicated by the attitude is probably misleading and is perhaps to be explained by a fault along Weeden Creek. Inasmuch as the basalt overlies the early andesitic series with no intervening arkoses, this series is also probably younger than the arkoses. The fragments of andesitic rock found in the arkoses, therefore, probably belong to older volcanics, associated with the ancient granite.

Correlation.—Professor Russell[1] describes, in the region not far south of Monte Cristo, a formation similar to the arkoses just described. This formation consists of 6,000 to 8,000 feet of arkoses and shales, with a thick, coarse conglomerate at the base, which rests upon the older rocks, consisting of ancient granite, schist, and serpentine. The formation has been named by Messrs. Russell and Smith the Swauk sandstone. Like the Monte Cristo arkoses, the Swauk sandstone underlies the volcanic series.

Mr. George Otis Smith, who has examined the specimens collected by the writer from the Monte Cristo district, has pronounced them to be identical lithologically with the Swauk sandstone of the Mount Stuart and Snoqualmie quadrangles.

Lithologically and in general age the arkose series resembles, and probably is at least partly contemporaneous with, the Puget group of Willis (see p. 796).

Geologic date.—The Swauk sandstone has been determined, on the basis of fossil leaves, to be Eocene[2] and of fresh-water origin.

EARLY ANDESITES, WITH ASSOCIATED TUFFS AND SLATES.

Distribution and general characteristics.—The rocks of this series occupy Seventy-six Gulch and the greater part of the mountains on both sides of the Sauk at Monte Cristo for a mile and a half below the town. The series consists chiefly of greenish altered andesites with tuffs of similar appearance derived directly from them. In addition to these there are green slaty tuffs, some of which contain a considerable proportion of quartz and so vary sometimes to fine impure quartz slates.

Composition and structure.—The andesites have invariably a fine-grained groundmass, generally microcrystalline and felty, often showing flow structure. Sometimes the groundmass was originally a glass, but has undergone devitrification. In the microcrystalline groundmass the only mineral recognizable is feldspar, which occurs in abundant tiny laths. The devitrified groundmass generally yields a very fine-grained aggregate of quartz and muscovite. The phenocrysts consist chiefly of feldspar, always altered, with pyroxene and hornblende, which are only occasionally found in their original condition, being typically entirely altered to pseudomorphs of chlorite. In one case a partly altered pyroxene was determined to be bronzite; the feldspars were determined to be chiefly andesine and oligoclase, with sometimes labradorite and anorthite. They are usually altered to calcite and other decomposition products.

Secondary minerals are always abundant, and are chiefly calcite, epidote, chlorite, pyrite, quartz, and sometimes biotite.

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[1] Twentieth Ann. Rept. U. S. Geol. Survey, Part II, 1900, pp. 119-120.

[2] Russell, op. cit., p. 123.

Metamorphism at contact with intrusive tonalite.—Near the contact with the great dikes of tonalite which cut this series the rocks become noticeably altered over a considerable zone. One of these great dikes cuts through the series at Twin Peaks, having its northeastern contact at the head of Seventy-six Gulch and Wilman Pass and its opposite one near Troublesome Pass, its width being about 5,000 feet. Near Wilman Pass, at a distance of about 1,200 feet from the contact, a specimen of andesite showed phenocrysts of feldspar considerably altered to calcite, with a microcrystalline groundmass consisting of feldspar, quartz, and tiny flakes of fresh brown and green biotite with some pyrite. The quartz, the biotite, and the pyrite are evidently all secondary and show silicification and the crystallization of the usual felty feldspathic groundmass. A specimen from the head of Seventy-six Gulch, in about the same zone, shows nearly the same characters, except that the feldspar phenocrysts are largely kaolinized, while in the microcrystalline groundmass, besides the predominant quartz, are small grains of fresh feldspar, evidently secondary. The structure is allotriomorphic and there are large grains of secondary pyrite. On the opposite side of the tonalite dike, on the northeastern side of Hubbart Peak, a specimen much like those described was examined, the feldspar phenocrysts being only partially attacked by metamorphism, while the groundmass was changed to fine quartz, sometimes with hexagonal outlines and sometimes allotriomorphic, with muscovitic and kaolinic material. This section contains scattered crystals and irregular fragments of chalcopyrite.

A specimen taken from an included band of andesite in the granite near the northeastern contact shows a more advanced stage of metamorphism. The feldspar phenocrysts are barely recognizable, being altered to an aggregate of small hexagonal quartz grains with some fibrous muscovite. The groundmass consists of hexagonal quartz, tiny flakes of biotite, grains of fresh secondary feldspar, pyrite, and a pale-green mineral which is probably a variety of hornblende.

At Wilman Pass, an estimated distance of 300 feet from the granite contact, the metamorphism has reached a still more advanced stage. In the hand specimen the rock resembles a fine-grained quartzite. A thin section shows to the naked eye cloudy, dark, rectangular cross sections indicating phenocrysts in a fine groundmass. Under the microscope the rock is seen to be made up of interlocking crystalline, generally hexagonal quartz, of small, nearly uniform size. The areas occupied by the rectangular sections above noted consist of hexagonal quartz, muscovite, chlorite, and small crystals of fresh secondary feldspar, all generally accompanied by residual portions of the decomposed original feldspar phenocrysts.

Summing up, the results of metamorphism of this dike are generally silicification with the development of mica. In this connection it is interesting to observe that, at the head of Seventy-six Gulch, near the tonalite contact, are many straggling coarse veins made up of quartz and biotite, the latter in places sometimes several inches across. In none of the specimens studied was there any schistosity, so that the alteration has been metachemic, and has been dependent upon solutions from the tonalite. This metachemic metamorphism has almost completely recrystallized the rock at a distance of 300 feet from the contact, and has produced marked changes at a distance of 1,200 feet.

The great tonalite mass which reaches from Glacier Creek across the mountains to Goat Lake has had a still greater metamorphic effect. Its entire width is unknown, but it has been observed for a width of at least 3 miles. It often, however, divides into separate dikes, which may trend, as in the mountains northeast of Monte Cristo, parallel with the general northwest direction of the main intrusion, or, as at Goat Lake, northeast, at right angles to the general direction. The greatest metamorphism is observed in the spaces between these branching dikes. The eastern contact of the main mass lies in Glacier Creek at the falls, and runs from here northwest along the mountain side. The contact is not simple, but is marked by a number of smaller marginal dikes. The rocks which these dikes cut are typically schistose, but in places, where they are less altered, they are seen to be the typical andesite and andesitic breccia of the earlier volcanic series, into which, indeed, they pass directly at a distance of several hundred feet from the main intrusive mass. At Glacier Creek two thin sections made from the same large specimen show, in one case, an andesitic tuff, and in the other case, a schist. In the first section are seen pieces of decomposed andesite in a fine andesitic matrix, impregnated with secondary quartz grains and dull-lustered metallic minerals. In the other section, one area, which is least altered, consists chiefly of secondary muscovite and quartz, thoroughly disseminated, with some feldspar, which is probably residual. Certain large areas of fine muscovite and residual feldspar between the fibers probably represent decomposed phenocrysts. Another part of the section, more completely altered, consists almost wholly of granular interlocking quartz with a tendency to idiomorphism. Schistosity in these rocks is noticeable, but slight.

This belt of schist lies on the southwestern contact of the granite dike all along the hill above Monte Cristo. In places the alteration has been more intense, resulting in a highly schistose or gneissic rock, fine grained and black, with many small quartz gash veins, giving it a gneissic appearance. A specimen of this rock microscopically examined is seen to be made up mostly of medium-grained quartz and very fine biotite, with no trace of the original rock. The structure gives evidence of shearing or flow under pressure.

On the mountain side between Glacier Creek and Sentinel Gap, which is on the divide between Monte Cristo and Goat Lake, there is a wedge of rocks of the andesitic series between two branching dikes of the tonalite. In its fresh state the intruded rock has a volcanic appearance, but a bed of conglomerate shows it to be a sedimentary tuff. The pebbles in this conglomerate consist, so far as examined, of decomposed andesite and a fine altered tuff, while the fine-grained rock interbedded with it is a fine slate containing quartz, feldspar, biotite, and hornblende. From here, as the granite is approached, the tuff begins to be schistose; farther on garnets and other crystals are developed in it; and still farther on it changes to a black gneiss with interbanded quartz veinlets like that previously described. The width of the metamorphic zone amounts to several hundred yards, perhaps a thousand feet.

On the other side of this same great tonalite dike we find it, on Osceola Pass above Goat Lake, intrusive into still more highly crystalline schists. These schists are cut by a number of smaller tonalitic dikes and by dikes of feldspar-hornblende rock which are apparently a phase of the main intrusion. A large portion of the schists are altered, although in different degrees of crystallization, to quartz-garnet-staurolite-biotite-schists, sometimes containing hornblende. Certain portions, however, are so little altered that their original nature is apparent.

In one case, where the shearing has been slight, there are found under the microscope certain microscopic areas which suggest original feldspar phenocrysts. The rest of the rock is fine grained, consisting mostly of fine quartz with small grains of feldspar, which is probably original, since it has largely turned to muscovite. In this rock there is also a little biotite and garnet. Another specimen proves to be a detrital slate, made up of very small quartz grains in a mat of kaolinic and muscovitic material. In two other cases the rock was evidently a very fine-grained quartzite. In one case the shearing had been very slight, resulting in the development of sparse muscovite.

A few of the larger quartz grains are of secondary growth, while the rest are plainly detrital. In the other case the rock consists of granular quartz, the grains being rounded and apparently detrital; the cement between the grains is kaolinic. The rock is cut across by fractures, along some of which shearing has produced the comminution of the quartz and the development of biotite, chlorite, and hematite (?).

Summing up the metamorphism due to the Glacier Creek–Goat Lake tonalite, we find that the recrystallization of the rock into which it intruded has extended, roughly speaking, a thousand feet or more. On the outer portions of the metamorphic zone the result has been simple silicification and the development of biotite, as was the case with the Wilman Pass intrusion. As the tonalite is approached the schist becomes coarser and often loses all trace of its original nature, and besides biotite, garnet, staurolite, and occasionally hornblende are developed. Sometimes the rock becomes gneissic in appearance, and contains interbanded quartz veinlets. In proportion as the recrystallization increases the schistosity does the same, being most pronounced near the tonalite contacts and disappearing entirely when the slightly altered or unaltered rock is reached. Microscopic study shows that the schistosity is due to pressure, which has produced shearing. It is plain, therefore, that the tonalite mass, on forcing its way up through the rocks of the volcanic series, has produced a shearing on both sides, and to this shearing the metamorphism is doubtless partly due. Therefore this case of contact metamorphism is one where the results are partly due to dynamic action produced by the tonalite intrusion, and partly to metachemic action produced by solutions from the tonalite.

Relative age.—The andesitic series is probably separated from the basal granitic rock by the arkose series, since it contains no granitic material. There is, indeed, some andesitic material in the arkoses, but this is probably derived from ancient volcanics. The basalts are probably younger than the arkoses, since they apparently cut them. All these basalts overlie the andesites with no intervening arkose, so the andesitic series seems to be intermediate between the arkoses and the basalts. It is older than the tonalities, which are intrusive into it, and also older than the later hornblende-andesite, which cuts the tonalite.

Correlation.—In the Snoqualmie quadrangle, farther south,[1] are two series of andesites, of which the earlier underlies heavy basalts and is cut by the Snoqualmie granite. This granitic rock is probably to be correlated with the tonalite of Monte Cristo, and the two andesites are very likely correlatable with the two andesites of this district also.

Geologic date.—The earlier andesites in the Snoqualmie region are probably Miocene, judging from their relation to the fossiliferous sandstones. In the Monte Cristo district a single fossil was found on the mountain slopes northeast of Glacier Creek. The rock is a fine, dark-green arkose slate or tuff with layers of conglomerate containing pebbles of andesite and fine impure sandstone. It is probable that this horizon lies well up in the andesitic series, although on account of the confusion introduced by the plicated structure of the region it is possible that its position is lower. The single fossil which was found was determined by Mr. T. W. Stanton to be *Corbicula pugetensis* White, which was originally described from the Puget group at Carbonado, Wash.

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[1] Mr. G. O. Smith, oral communication. See also Tertiary granite in the northern Cascades, by Smith and Mendenhall: Bull. Geol. Soc. America, Vol. XI, pp. 225-226.

The genus *Corbicula* is characteristic of the Puget strata, and is a fresh or brackish-water form, but not marine.[1] The Puget group of strata, as described by Mr. Bailey Willis,[2] consists of upward of 10,000 feet of sandstones, derived chiefly from granite, and shales which are often carbonaceous and contain coal beds. The series contains leaf impressions and sparse molluscan fauna. The older rocks are usually granite or crystalline schists, serpentinic or chloritic.[3] Metamorphic schists and limestones of Carboniferous or Triassic age occur unconformably beneath the Puget group in the Skagit district.[4] This group extends from beyond the British boundary southward almost to the Columbia, and from the Pacific eastward into the Cascades to heights as much as 5,000 feet above the sea. It is overlain by Tertiary and later volcanic rocks.

Lithologically and stratigraphically the bulk of the Puget group, as above described, corresponds to the arkose series of Monte Cristo, in which also some little lignite probably occurs. If the horizon in which the fossil was found in Monte Cristo has been correctly placed, it shows the extension of the Puget fauna upward beyond the arkose series. The Puget group was at first supposed to be Cretaceous,[5] but later study by Dr. Knowlton of the fossil flora places it probably in the upper Eocene or lower Miocene.[6]

From all the data which we have, therefore, we may class the andesitic series as lower Miocene.

TONALITE AND DACITE.

TONALITE.

Distribution.—Tonalite makes up Mystery Hill and the greater part of the mountain northeast of Glacier Creek. Another large mass is found at the head of Seventy-six Creek and constitutes the rock of Twin Peaks. Besides these two large masses there are frequent smaller dikes. The general trend of the tonalite intrusions is about north-northeast, but in the Goat Lake district dikes were noted at right angles to this.

General description.—In the field the tonalite strongly resembles granite, being composed chiefly of quartz, feldspar, and hornblende. The microscope brings out its true character. The essential minerals are found to be feldspar, hornblende, and biotite, with occasional augite and hypersthene, and an abundant gray metallic mineral which is probably magnetite. The feldspar varies between oligoclase and bytownite, in general indicating a rather basic dioritic rock. The secondary minerals are actinolite, chlorite, epidote, pyrite, calcite, kaolin, etc. The structure of the rock is ophitic to nearly hypidiomorphic granular, with a slight tendency to porphyritic. The feldspar is generally the oldest of all the minerals except the occasional pyroxene; the quartz is youngest.

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[1] On invertebrate fossils from the Pacific coast, by C. A. White: Bull. U. S. Geol. Survey No. 51, 1889, pp. 56, 60.

[2] Tenth Census Report, Vol. XV, p. 789. Geologic Atlas U. S., folio 54, Tacoma, Wash., 1899, p. 2. Some coal fields of Puget Sound: Eighteenth Ann. Rept. U. S. Geol. Survey, Pt. III, 1898, p. 400.

[3] Bailey Willis, Tenth Census Report, p. 760.

[4] Bailey Willis, Eighteenth Ann. Rept. U. S. Geol. Survey, Pt. III, 1898, p. 403.

[5] On invertebrate fossils from the Pacific coast, by C. A. White: Bull. U. S. Geol. Survey No. 51, 1889, p. 169.

[6] Some coal fields of Puget Sound, by Bailey Willis: Eighteenth Ann. Rept. U. S. Geol. Survey, Pt. III, 1898, p. 403.

Relative age.—The tonalite cuts the arkose series and the early andesites. It is itself cut by the later andesite. It is also probably cut by the basalt, but this was not definitely determined. It is not found, however, in the basaltic area, so it is probably concealed under these lava flows.

Correlation.—The tonalite is apparently correlatable with the Snoqualmie granite, which has been studied by Messrs. Smith and Mendenhall in the region south of Monte Cristo.[1]

Geologic date.—According to Messrs. Smith and Mendenhall the Snoqualmie granite is Miocene.

TONALITE-PORPHYRY.

Distribution.—Tonalite-porphyry is found in numerous dikes, as, for example, on the south side of Silver Lake, on the southeast side of Silver Creek opposite Mineral City, and near the mouth of Sunday Gulch, in the vicinity of Monte Cristo.

Description.—The rock is porphyritic, with a fine-grained allotriomorphic granular groundmass; it frequently shows flow structure. The phenocrysts are chiefly feldspar and hornblende, while the groundmass consists of lath-shaped feldspar, with allotriomorphic quartz and hornblende.

Relation to tonalite.—The tonalite-porphyry is evidently only a textural phase of the tonalite, having consolidated in this form in the smaller dikes. The occasional porphyritic tendency in the larger tonalite masses shows the relation of the two rocks.

DACITE.

Distribution.—Dacite was found in two places—one in Pearsall Gulch and one at the head of Silver Creek. A specimen of the latter was collected by Mr. Willis.

Description.—Dacite from Pearsall Gulch has a porphyritic structure and a microcrystalline granular groundmass. The phenocrysts are hypersthene and feldspar, and the groundmass is quartz, feldspar, biotite, augite, and magnetite. The dacite from Silver Creek has phenocrysts of feldspar and quartz in a glassy, semidevitrified groundmass.

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[1] Tertiary granite in the northern Cascades: Bull. Geol. Soc. America, Vol. XI, p. 225.

Relation to tonalite and tonalite-porphyry.—The dacite in Pearsall Gulch is in close proximity to tonalite and tonalite-porphyry, and all are very likely parts of the same large dike. That at the head of Silver Creek occurs in a complex of tonalite dikes, and is probably of the same age.

The tonalite, tonalite-porphyry, and dacite are probably, therefore, textural variations of the same rock, differentiated on cooling.

RHYOLITE.

Distribution.—Rhyolite occurs in small quantity in this district. It was observed in two places—in Pearsall Gulch and in Silvertip Gulch. Between these two localities it is probably continuous, forming a narrow belt running in a northeasterly direction, but on account of its slight importance it has not been represented on the map.

Description.—The rhyolite from the above-mentioned localities is similar. It possesses a microspherulitic, partly microcrystalline groundmass with phenocrysts of quartz and feldspar, fragments of bleached biotite, and areas of calcite and iron oxide representing the decomposition of ferromagnesian minerals. The groundmass appears to be mostly quartz and feldspar.

Relative age.—It is possible that the rhyolite is intrusive, but it has rather the appearance of a lava or surface flow. If it is the latter, then, from its position between the early andesites and the basalts, it is younger than the former and older than the latter.

Correlation.—Russell and Smith note on the Teanaway River in the Mount Stuart quadrangle a rhyolite in small quantity whose stratigraphic position is uncertain, but which may correspond to the Monte Cristo rock.

BASALTIC ROCKS.

Distribution.—The basalts are found in the northwestern part of the area shown on the accompanying map (Pl. LXXX), where they occupy an area between the early andesites and the arkose series. They are also found in occasional dikes cutting the early andesites and the arkoses.

Description.—The nature of the basalt is nearly the same in the different localities studied. In general, it may be classed as a pyroxene-olivine-basalt. The structure is exceedingly fine grained, like the groundmass of ordinary lavas, but there are no phenocrysts. The texture is fine holocrystalline micro-ophitic, sometimes glassy. There is sometimes a fluxional structure. Vesicles are frequent, and are sometimes filled with decomposition products so as to become amygdules. The chief minerals are brown augite, feldspar, and olivine. As decomposition products, chlorite, serpentine, actinolite, uralitic hornblende, and calcite occur.

Relative age.—The basaltic dikes appear to cut the arkoses and the early andesites. The main mass of basalts, which is probably a surface flow, appears fresher than the early andesite series. If it is later than this series it is probably also later than the rhyolite which lies between the two. It is not cut by tonalite, but overlies and seems to hide it, and appears to be younger than the tonalite.

Correlation.—Russell and Smith have mapped portions of the great basaltic lavas in the Mount Stuart quadrangle and regions farther southeast as augite-olivine-basalt. This basalt is frequently cellular, often amygdaloidal. It is succeeded in Yakima County by flows of hypersthene-andesite, much later in age, probably late Pliocene or Pleistocene.

Mr. G. O. Smith has also recognized a probable equivalent of the Monte Cristo basalt in the Yakima basalt, which occupies about the same relative position in the geologic section.

Geologic date.—According to Messrs. Russell and Smith the Yakima basalt, judging from the relation to associated fossiliferous strata, is Miocene.

ENSTATITE-PERIDOTITE.

Distribution.—Of this rock only a single dike was found. This cuts the arkose series near the head of Silver Creek, in Molybdenum and Jumbo gulches. It runs in a direction slightly east of north.

Description.—The rock has a granular structure and a medium-coarse texture. It consists of olivine and enstatite, the former predominating. There is a little magnetite. The alteration products are serpentine, talc, and bastite (?).

Relative age.—This rock cuts the arkose series; otherwise its age is not known. It may be a phase of the basalts just described. Saxonite has been described by Mr. Diller in Oregon,[1] but there its relations are such as to indicate a greater age than in the Monte Cristo region. There is also a large amount of peridotite in Washington, which is largely altered to serpentine, but so far as its relations have been studied the serpentine appears to be older than the arkose series, and is, therefore, of a different age from the Monte Cristo occurrence.[2]

LATER ANDESITES, TUFFS, AND BRECCIAS.

Distribution.—The later andesites occupy the crest of the ridge between Glacier and Seventy-six gulches, and extend southward so as to form Columbia Peak and the region east of Twin Lakes. The andesitic tuffs, breccias, and flows which occur on the summit of the ridges directly southwest of Monte Cristo also probably belong to this group.

Description.—A specimen of the andesite from the ridge between

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[1] Bull. U. S. Geol. Survey No. 60, 1890, p. 23.

[2] The Clealum iron ores, Washington, by Smith and Willis: Trans. Am. Inst. Min. Eng., Washington meeting, Feb., 1900.

Glacier and Seventy-six gulches possesses a groundmass varying from microcrystalline to glassy, which contains many feldspar phenocrysts. Specimens collected by Mr. Smith near Twin Lakes are of glassy spherulitic lava, which contain augite and seem to be basic andesite. In Pearsall Gulch a dike which cuts the tonalite is porphyritic, with a cryptocrystalline to microcrystalline groundmass and phenocrysts of hornblende, pyroxene, and feldspar. The feldspar is rather basic, being once determined as anorthite. The pyroxene is, in part at least, diopside. Decomposition products are fibrous actinolite, chlorite, calcite, etc.

In general, therefore, the rock seems to be a basic pyroxene-andesite.

Relative age.—In several places this series contains fragments of schist and granitic arkose. Since the schist is a product of the tonalite intrusion, the andesite is younger than the tonalite, the earlier andesites, the arkoses, and the early granites. In the neighborhood of Twin Lakes Mr. Smith found the lavas resting upon an eroded surface of tonalite. In Pearsall Gulch a dike of later andesite cuts the tonalite and the early andesite series.

The later andesite series lies nearly horizontal or is gently inclined and appears unconformable to all the later rocks which have been described, and which have been found, so far as studied, highly folded. Subsequent to the folding there was deep erosion, capable of exposing the tonalite (originally a somewhat deeply buried rock), so that the andesitic flows could be laid down upon it. This deep erosion seems to have been that which produced the old Cascade lowland plain.

Correlation.—Professor Russell[1] speaks of a flow of hypersthene-andesite as one of the latest features in the volcanic series in Yakima County.

Glacier Peak, also described by Professor Russell,[2] lies only about 40 miles northeast of Monte Cristo. It is an extinct volcanic cone composed of andesite and pyroclastic material. Professor Russell believed that the volcano originated after the development of the Cascade lowland plain, and probably also after its upheaval to form the Cascade Plateau. He regards it as belonging in the same category as Mount Baker, Mount Rainier, etc., which are all extinct andesitic cones.

The rocks of Mount Rainier have been described by Mr. G. O. Smith.[3] The rock is a pyroxene-andesite, often basic, and there are large amounts of pyroclastic material. The volcanic rocks rest upon an elevated platform of granitic rocks, which have been exposed by erosion.

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[1] A geological reconnaissance in central Washington, by I. C. Russell: Bull. U. S. Geol. Survey, No. 108, 1893, p. 64.

[2] Twentieth Ann. Rept. U. S. Geol. Survey, Pt. II, 1900, pp. 131, 135.

[3] Eighteenth Ann. Rept. U. S. Geol. Survey, Pt. II, 1898, p. 416.

The later andesites of Monte Cristo and those of Glacier Peak and Mount Rainier have many features in common. They are all andesites, and, so far as studied, pyroxene-andesites. They are all the products of explosive eruption from separate vents. They are in each case later than all the other rocks of the country, and in each case rest upon the upturned and deeply eroded surface of the older rocks. The Monte Cristo andesite is evidently older than the existing volcanic cones, since it has undergone greater erosion, yet the difference of age indicated is relatively small, and all the different occurrences may be considered as manifestations of a single episode of volcanic activity which extended over a considerable period.

Geologic date.—As just stated, Professor Russell believed that the Glacier Peak andesite was extruded after the formation of the Cascade lowland plain, and probably after its elevation. According to Russell, the planation took place in the late Tertiary, and perhaps was prolonged into the Pleistocene, so that the uplift was late Pliocene or early Pleistocene.[1] The Glacier Peak andesite is therefore Pleistocene, as are the other extinct andesitic cones. In Monte Cristo the andesite appears to have been later than the folding and planation, and the comparatively rough topography of the old surface observed under it may indicate that the present cycle of erosion had begun before its outpouring.[2] Nevertheless, the relatively greater amount of erosion in the andesites themselves indicates that they are slightly older than those of Glacier Peak, Mount Rainier, etc.

In general, therefore, the epoch of later andesitic volcanic activity in Washington appears to have lasted from the late Pliocene to the late Pleistocene.

JOINTING.

The jointing of the rocks of the Monte Cristo district is a conspicuous geologic feature. It also exercises an important influence on the landscape, the sharp mountains having the appearance of being thoroughly riven, in places almost sliced, by the chief joints. Gulches, crags, and the general detail of the scenery have originated by erosion along the joints. The most powerful set has a strike averaging 65° or 70° E. and a dip averaging 70° NW. The next most prominent set has the same strike but a flatter dip, averaging about 30° NW. These prominent joints cut all the rocks, being shown even in the later andesites (Pls. LXXIX, *B*, and LXXX).

AGE OF JOINTS.

The later andesite of Monte Cristo was laid down on the folded and eroded surface of the Cascade lowland plain, as above stated, but it was also laid down previous to the powerful erosion which has left it as cliffs on the tops of mountains. This erosion immediately followed the uplift of the lowland plain to form the Cascade Plateau, so that the andesite was laid down just previous to the uplift or during its first stages. The joints, since they traverse the andesites, are somewhat later. So far as the writer can ascertain, this system of joints, which is strongly marked throughout the Cascades, has not cut the later andesitic Pleistocene volcanic cones of Glacier Peak, Mount Rainier, etc., which were formed after the uplift but still some time back of the present. Therefore, the jointing was in general contemporaneous with the uplift, and probably closely connected with it genetically. Its age must be late Pliocene or early Pleistocene.

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[1] Twentieth Ann. Rept. U. S. Geol. Survey, Pt. II, 1900, pp. 128, 144.

[2] This was probably true of the Mount Rainier lava. G. O. Smith, Mazama, October, 1900, pp. 20, 21.

The direction of the chief jointing is N. 65° or 70° E., and is very nearly at right angles to the general trend of the Cascades. This transverse system of lines of weakness manifested by cross folds, faults, and joints has been referred to by Professor Russell as follows:[1]

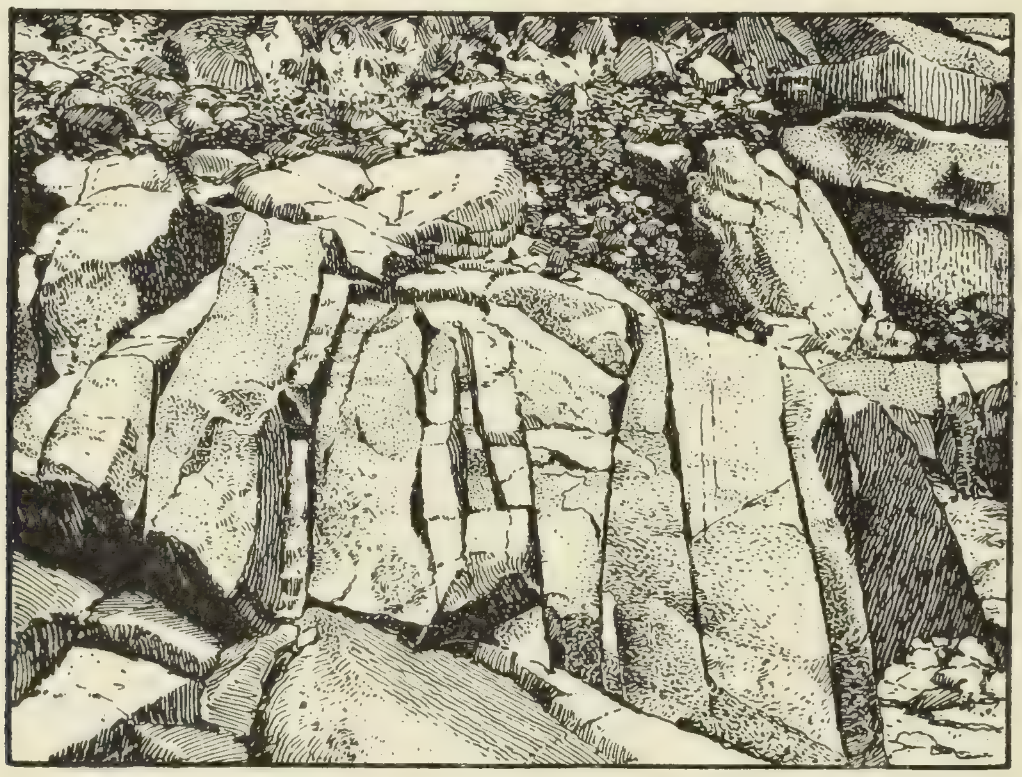

FIG. 90.—Sheeting in granitic arkose, head West Fork Silver Creek.

> In addition to the north-south folds just referred to, which have their longer axes parallel with the general trend of the Cascade Mountains, there are a number of folds and faults which diverge at a high angle to the direction of the main structure lines. * * * Thus, throughout the central portion of the Cascade region in Washington, especially on its eastern side, there are strongly pronounced structural lines indicated principally by faults which branch off at high angles from the main north-south axis of the mountains. The general trend of these lateral fractures is, in fact, nearly at right angles to the longer axis of the Cascades and of the principal folds of which that range is composed. It will perhaps be of interest in the future, when the structure of the Cascade Mountains is more critically studied, to note that the fissure veins in the Slate Creek district, traversing the Similkameen [Methow] formation, also trend nearly east and west, or at right angles to the folds in the rocks where they occur. * * * The age of the secondary disturbances just described is indicated by the fact that they involve Tertiary sediments and the associated Columbia [River] lava, and hence occurred in late Tertiary or post-Tertiary time, and contemporaneously,

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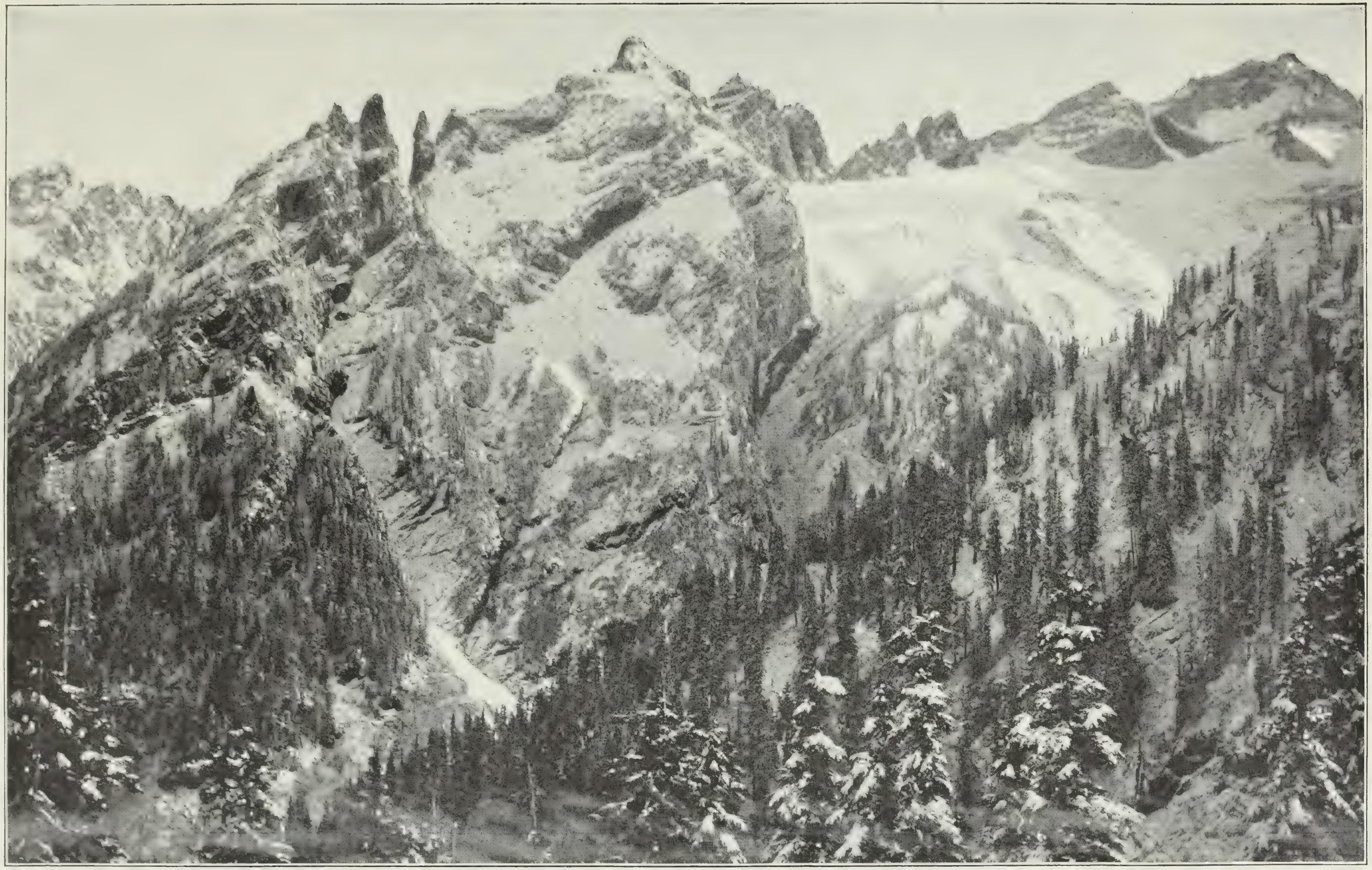
[1] Twentieth Ann. Rept. U. S. Geol. Survey, Pt. II, 1900, p. 138.



WILMAN PEAK AND GLACIER FROM WEST SIDE OF SEVENTY-SIX GULCH.

Shows pinnacles produced by erosion along fault zones.

as nearly as can be judged, with the latest great upward movement in the Cascade Mountain mass. In some instances the secondary folds and faults referred to originated after the initiation of the present system of drainage.

It must not be overlooked, however, that some of the joints may be of earlier origin than the most prominent sets, and were perhaps attendant on pre-planation folding.

RÉSUMÉ OF GEOLOGIC HISTORY.

The history of the Monte Cristo district appears to have been much the same as that which has been worked out for the rest of the Cascades. The oldest of the recognized rocks is a granitic terrane, which on long exposure to erosion during earlier Tertiary time yielded several thousand feet of arkoses. Then began a period of volcanic activity, commencing with the extrusion of abundant andesites. The presence of water-laid tuffs in the andesitic series shows that much of the material was laid down under water. After the andesites came the intrusion of tonalite, and this was succeeded, very likely with an erosion interval between, by scanty rhyolite, and this by abundant flows of olivine-basalt. Subsequently the whole series was folded and eroded. This sequence of events occupied the time until the close of the Tertiary; then the later andesite was poured out, just previous to and in the earlier stages of the uplift of the lowland plain of erosion into a plateau, this uplift being accompanied by profound fracturing and slight faulting, chiefly in an east-west direction. After this there were erosion and ore deposition, which occurred mostly during the Pleistocene. A deposition of sulphides has taken place in the Monte Cristo district, chiefly along the joints. Hence, so far as we can judge, the ore deposition began in the late Pliocene or early Pleistocene.

STUDY OF THE ORES.

NATURE OF ORES.

The chief ores in the Monte Cristo district consist of pyrite, pyrrhotite, arsenopyrite, blende, galena, and chalcopyrite. Realgar as an alteration product from arsenopyrite is common. Among the rarer minerals are chalcocite, bornite, molybdenite, and stibnite. Metallic arsenic is said to have been found on Goat Lake not far northeast of Monte Cristo. Among the oxidation products of the sulphides are malachite, limonite, hematite, melaconite, and scorodite.

These ores carry in general relatively small amounts of silver and gold. In the Monte Cristo mine, according to reliable information, the average ore at some distance below the surface carries 0.6 of an ounce of gold and 7 ounces of silver. The maximum content is 1.4 ounces of gold and 18 ounces of silver. The surface ores in the same mine carry an average of 0.95 ounce of gold and 12 ounces of silver.

The chief gangue minerals of the ores are quartz and calcite. Epidote and blue soda-amphibole are minerals developed in the wall rock near the veins, the former chiefly in the andesites and the latter in the tonalites. These might be considered gangue minerals, although they do not, in general, actually form part of the veins.

WHEN THE ORES WERE DEPOSITED.

Relation to Cascade uplift.—From what has already been said it appears that the ore deposition can hardly have begun earlier than the uplift of the Cascade plateau, at which time the chief joints were probably developed.

Relation to dynamic movements.—It may be made as a general statement, the truth of which is only emphasized by the occasional exceptions to it, that there has been surprisingly little post-mineral movement in the ores and inclosing rocks. To one who has had a large experience in ore deposits this is immediately striking. It becomes more so when we study the history of the Cascades and find how extremely active was Tertiary deformation, and that it was prolonged into the Pleistocene. The conclusion arrived at is that the ores have all been deposited during a period geologically not far removed from the present.

Relation to present topography.—Immediately on the uplift of the Cascade plateau there was inaugurated a remarkably active system of erosion, so active that at the present time the master streams have practically finished their share of the work of degradation.[1] Therefore ore deposition has taken place chiefly during the development of the modern topography.

Duration of ore deposition.—The question of the beginning of ore deposition is thus fairly well answered. The other two questions which naturally arise are: Was the ore deposition intermittent or regular? and When did it close?

Evidence will be set forth later to show that solution and deposition of metallic minerals in the form of ore deposits have been going on in very recent times—indeed, probably since the formation of exactly the present topography. The ores will presently be classified into two chief zones: (1) A zone of surface ores marked by a proportion of blende, galena, and chalcopyrite relatively much larger than that found in the deeper ores, and also marked by greater abundance of gold and silver; (2) a deeper zone consisting essentially of the pyrites, chiefly arsenopyrite, and containing a smaller but more uniform content of the precious metals. It is within the surface zone that we have evidence of deposition up to within the present geologic episode, and probably up to the present day, but this, of course, may be possibly a reconcentration, re-solution, and redeposition of earlier deposits formed under quite different circumstances. In order to find the duration of the primary ore deposition we should confine our inquiries to the lower, evidently unmodified deposits.

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[1] Russell, Twentieth Ann. Rept. U. S. Geol. Survey, Pt. II, 1900, p. 146.

In the course of the hasty examination of the district there was suggested, but not proved, a slight relation of the lower unaltered ores to the surface. Many of the smaller veins and some of the larger ones, which at the surface show several inches or even several feet of ore, when followed away from the surface wedge out and finally disappear in a barren fracture. This is suggestive but not trustworthy, for the ore veins in Monte Cristo are not continuous but contain a series of ore lenses found at intervals along the main lead. On the other hand, it appears that the deeper workings have not yet brought to light any such important ore bodies as are frequently found near the surface.[1]

So far as can be seen the same conditions prevail to-day as have existed ever since ore deposition began. Therefore there is no reason to suppose that it has yet finished. The solution and redisposition of sulphides, probably going on now near the surface, producing concentration, may be contemporaneous with the primary deposition of leaner sulphides at a somewhat deeper zone.

Conclusion.—Thus the chief ore deposition began in the late Pliocene or early Pleistocene and has continued contemporaneously with the development of the present topography down to the present day.

WHERE THE ORES WERE DEPOSITED.

The loci of mineralization in the Monte Cristo district may be classified as follows:

(1) Mineralization along joints.
(2) Mineralization along bedding planes.
(3) Mineralization at contacts.
    (*a*) Tonalite contact.
    (*b*) Enstatite-peridotite (serpentine) contact.

MINERALIZATION ALONG JOINTS.

To this class belongs perhaps 99 per cent of the entire mineralization of the district.

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[1] The phrase "near the surface" is here used roughly and requires some modification. If any relation between the primary ores and the surface actually exists, it is between these ores and the belts of uniform conditions of circulation of atmospheric waters. In a region where the rocks are equally permeable these zones of equable circulation may be regularly governed by the topographic surface, but where the rocks are unequally fissured, allowing in some places more ready access to the atmospheric waters than in others, the hypothetical surface of equal circulation, although always ultimately dependent upon the topographic surface, will become exceedingly irregular and will deviate locally very widely from it.

GENERAL ATTITUDE OF UNMINERALIZED JOINTS.

The following table gives the result of many observations of the attitude of the chief joint systems:

Attitude of the chief joint systems.

Strike.	Dip.	Locality.
N. 98 E	NW. 18	Poodle Dog trail, above Monte Cristo.
N. 83 E	NW. 75	Head Seventy-six Gulch.
N. 79 E	(3 S.)[a]	Falls of Glacier Creek.
N. 78 E	NW. 20 (1 S.)[a]	Head Seventy-six Gulch.
N. 75 E	NW. 40 (1 S.)[a]	Hubbart Peak.
N. 75 E	90	Do.
N. 73 E	NW. 70	Twin Peaks.
N. 70 E	NW. 20 (1 S.)[a]	Mystery Hill.
N. 70 E	NW. 70	Do.
N. 70 E		Between Sentinel and Cadet peaks.
N. 70 E	SE. 50	Lower Seventy-six Gulch.
N. 70 E	SE. 65	East of Weeden Creek.
N. 68 E	NW. 70	Silver Lake.
N. 68 E	SE. 80	Head West Fork Silver Creek.
N. 67 E	NW. 70	Monte Cristo Mountain.
N. 67 E	SE. 30	Do.
N. 66 E	NW. 70	Falls of Glacier Creek.
N. 66 E	NW. 30 (1 S.)[a]	Do.
N. 65 E	NW. 80	Poodle Dog trail, above Monte Cristo.
N. 60 E	90	Sunday Gulch.
N. 58 E	NW. 80	Wilman Peak.
N. 58 E	NW. 35 (1 S.)[a]	Do.
N. 50 E	NW. 60	Above Goat Lake.
N. 40 E	NW. 70 (1 S.)[a]	Poodle Dog trail, above Monte Cristo.
N. 38 E	(2 S.)[a]	Mouth Jumbo Gulch, Silver Creek.
N. 33 E	NW. 80 (1 S.)[a]	Twin Peaks.
N. 10 E	NW. 70 (1 S.)[a]	Molybdenum Gulch.
N. 3 E	(3 S.)[a]	Head West Fork Silver Creek.
N. 27 W	90 (2 S.)[a]	Twin Peaks.
N. 27 W	(4 S.)[a]	Falls of Glacier Creek.
N. 30 W	NE. 50 (2 S.)[a]	Poodle Dog trail, above Monte Cristo.
N. 37 W	NE. 65 (2 S.)[a]	Head Seventy-six Gulch.
N. 45 W	(2 S.)[a]	Falls of Glacier Creek.
N. 67 W	NE. 85	Mouth Jumbo Gulch, Silver Creek.
N. 77 W	(1 S.)[a]	Head West Fork Silver Creek.
N. 82 W	NE. 10 (1 S.)[a]	Glacier Creek, east side.
N. 82 W	NE. 65	Do.
N. 82 W	NE. 70	Molybdenum Gulch.

[a] 1 S., 2 S., 3 S., and 4 S. signify, respectively, that the joints belong to subordinate sets of the second third, and fourth order of importance. The joints of the more important systems are also always present at each of these localities.

The statements conveyed in this table have been graphically represented in the following diagrams (figs. 92 and 94). From the diagram showing the plotted strikes it appears immediately that the chief jointing strikes in an east-northeast direction. There are four subordinate systems observable. One strikes northeast and another northwest, these two being nearly at right angles. Another strikes a little north of west, or perhaps west-northwest, and a fourth, represented by a single line, strikes a little east of north, or perhaps north-northeast, these two again being nearly at right angles. In the diagram showing the plotted dips the chief dip of the northeast-southwest joints is seen

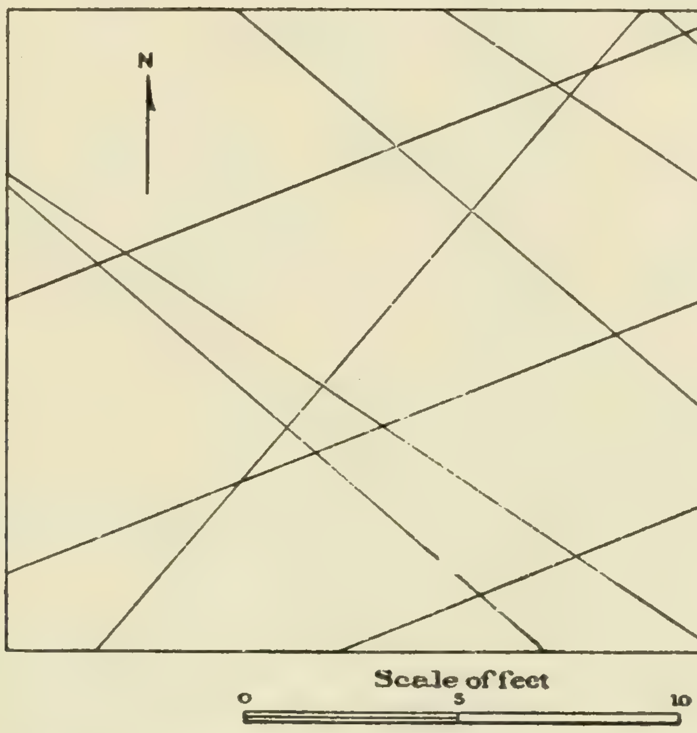


FIG. 91.—Sketch diagram of joints on horizontal tonalite surface, Glacier Creek.

to be about 65° or 70° NW., varying from this to vertical. There is a subordinate set dipping between 30° and 40° NW., and another dipping 20° NW., while a few joints have a southeast dip. Summarizing, the chief joint system has a strike N. 65° or 70° E. and a dip 65° or 70° NW. The principal subordinate sets are (1) strike N. 45° E. on the average, dip about 70° NW.; (2) strike about N. 45° W., on the average, dip about 70° NE.; (3) strike N. 65° or 70° E. dip about 30° NW.· also (4) strike N. 10° E. (fig. 2.)

GENERAL ATTITUDE OF VEINS.

We may compare this tabulation of the attitude of unmineralized joints with the following table of veins formed along joint planes, in order to see whether the veins have followed any systems of joints by preference.

Attitude of some of the principal veins.

Strike (average).	Dip (average).	Names of mines or prospects.
East	S. 75 (S.)[a]	Goat Lake mines.
N. 85 E.	NW. 65	Vein in side canyon, north of Glacier Creek.
N. 80 E.	NW. 68	Tunnel west side Seventy-six Gulch.
N. 78 E.	NW. 80	Seattle, Red Gulch.
N. 75 E.	NW. 75	Tunnel west side Seventy-six Gulch.
N. 74 E.	NW. 78	Ibex.
N. 73 E.	SE. 80	Silver Star.
N. 73 E.	NW. 65	Mystery and Pride.
N. 71 E.	NW. 70	Golden Cord.
N. 70 E.	90	Tunnel north of falls, Glacier Creek.
N. 70 E.	NW. 25 (S.)[a]	Tunnel west side Seventy-six Gulch.
N. 68 E.	90	Tunnel, Silver Creek, West Fork.
N. 68 E.	NW. 70	Threadwell.
N. 68 E.	SE. 83	Louise and Edison.
N. 68 E.	SE. 70	Canton, Silver Creek.
N. 65 E.	NW. 65	Seventy-six.
N. 65 E.	90 (S.)[a]	Vein in side canyon, north of Glacier Creek.
N. 60 E.	NW. 70	Sydney.
N. 42 E.	SE. 70	Upper Florence and Olive May.
N. 40 E.	NW. 70	Tunnel above Poodle Dog Trail.
N. 37 E.	SE. 73	Goat Lake mines.
N. 33 E.	NW. 65	O. and B.
N. 30 E.	NW. 45	Tunnel, Pearsall Gulch.
N. 10 E.	NW. 87	Rainy.
N. 10 E.	NW. 70	Lost Hope.
N. 10 E.	SE. 80	Tunnel 200 feet west of Olive May.
N. 30 W.	NE. 50 (S.)[a]	Tunnel above Poodle Dog Trail.
N. 47 W.	(S.)[a]	Tunnel, Silver Creek, West Fork.
N. 70 W.	NE. 75 (S.)[a]	Seventy-six.
N. 80 W.	NE. 60 (S.)[a]	Tunnel north of falls, Glacier Creek.
N. 82 W.	NE. 65	Tunnel in Glacier Gulch, north of Pride.
N. 82 W.	NE. 70 (S.)[a]	Lost Hope.

[a] Subordinate veins in tunnels where the predominating vein has another direction.

The diagrams, figs. 93 and 95, presenting graphically the information conveyed in the table, show practically the same features as the diagrams of unmineralized joints. The east-northeast system of veins is overwhelmingly preponderant. All of the other subordinate systems of unmineralized joints are also sometimes occupied by veins. From a comparison of the diagrams showing the strikes of joints and the strikes of veins, it is clear that the mineralization has had no special preference for veins of some systems over those of others. A comparison of the tables of dips of unmineralized joints and veins, however, seems to show some slight selective tendency of the veins, although the data are, of course, inadequate. The veins mainly seem to have preferred the more steeply dipping joints to those which lie flatter.

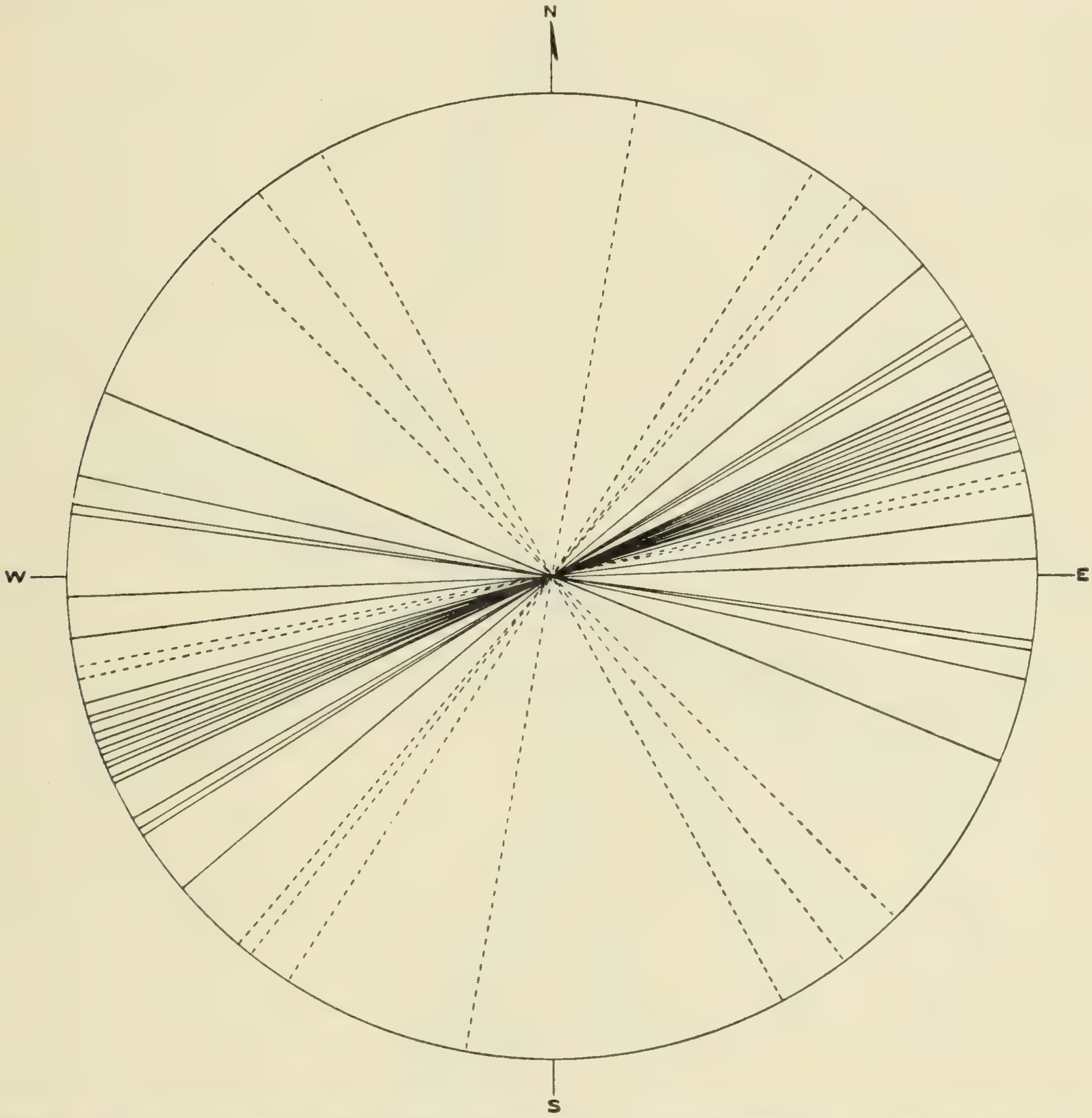


FIG. 92.—Tabulation of strikes of principal observed joints (unmineralized). Black lines indicate predominant sets of joints. Dotted lines indicate subordinate sets, always in localities where a predominant set is present.

STUDY OF MINOR COMPLICATIONS OF JOINTING.

Variations in intensity of jointing.—Although the rocks of the whole district are thoroughly jointed, the distribution of the jointing is not strictly equable. This irregularity is best illustrated by the predominant steeply northwesterly dipping and east-northeast striking set. To one who looks over the country from some high point it is plain that there is a broad belt of maximum east-northeast jointing which runs from Goat Lake, just southeast of the town of Monte Cristo, through the Silver Lake district and down Silver Creek. The course of Silver Creek above Mineral City is along this belt of maximum jointing, and very likely was primarily determined by it. The width of the belt is irregular, but may be averaged as between 1 and 2 miles.

Within this belt there are also minor differences in intensity of jointing. Along certain belts the parallel northeast fractures are much more closely set together than in others, in some cases amounting to a sheeting of the rock so marked as to produce gulches by reason of the easy erosion afforded by the fractured material. Most of the steep spires and crags of the mountains, such as those of the Wilman Peak district, are caused by erosion acting on rocks thus irregularly jointed.

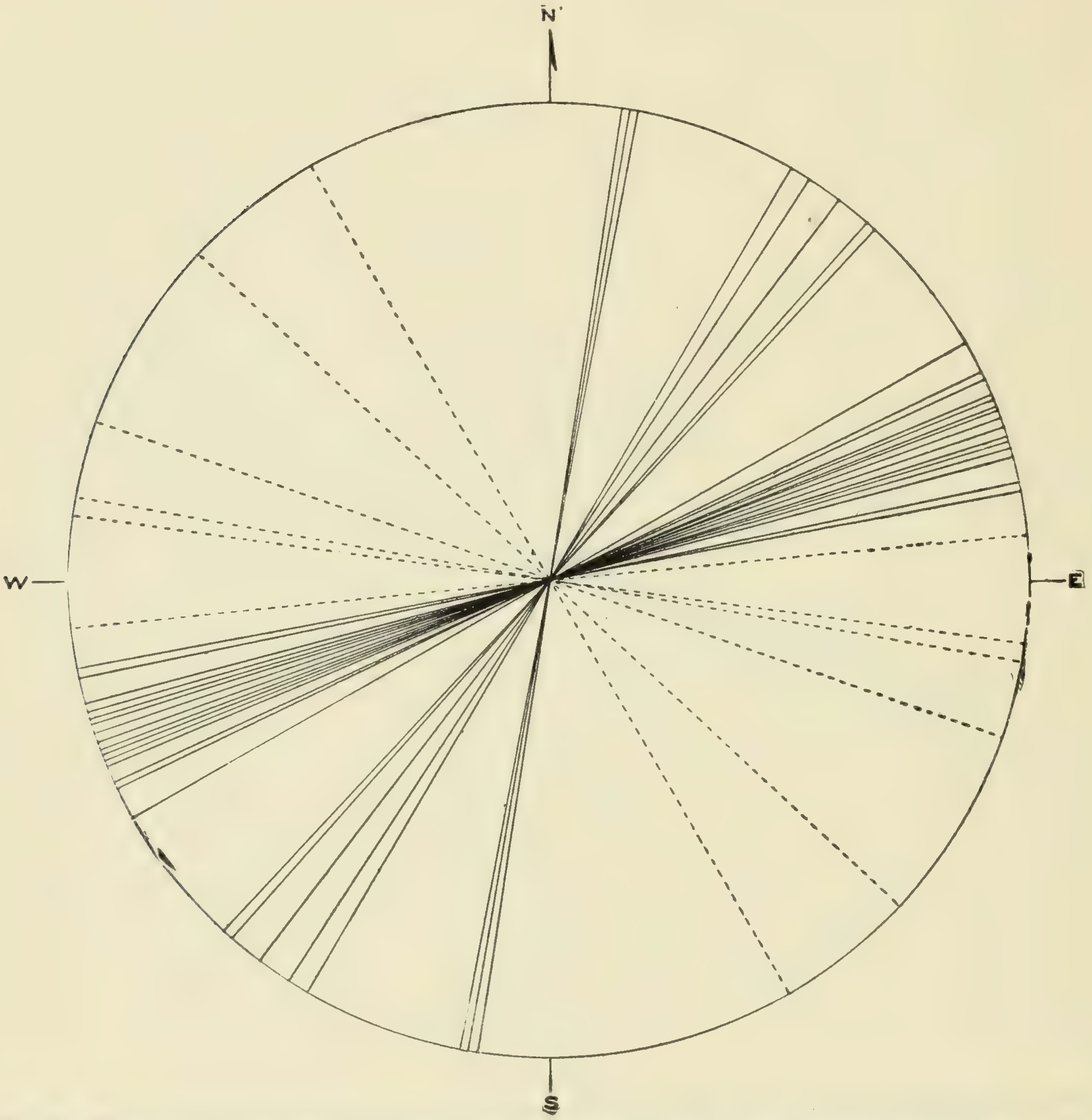


FIG. 93.—Tabulation of strikes of principal observed veins. Black lines indicate predominant veins. Dotted lines indicate subordinate veins, always in localities where a predominant set is present.

Imbricating joints.—One of the most common minor phenomena of jointing observed is imbrication. A joint stops entirely, and the strain which it accommodated has been taken up by a parallel joint, usually only a few inches distant. This parallel joint may terminate within a short distance in both directions, and its strain may in turn be taken up by an overlapping joint. The accompanying figures (figs. 96 and 97) illustrate this imbrication on a small scale. There is some reason to suspect that this minor structure is present also on a larger scale and that some of the slight vein complications observed in mining operations may be due to the overlapping of one vein upon another in this way.

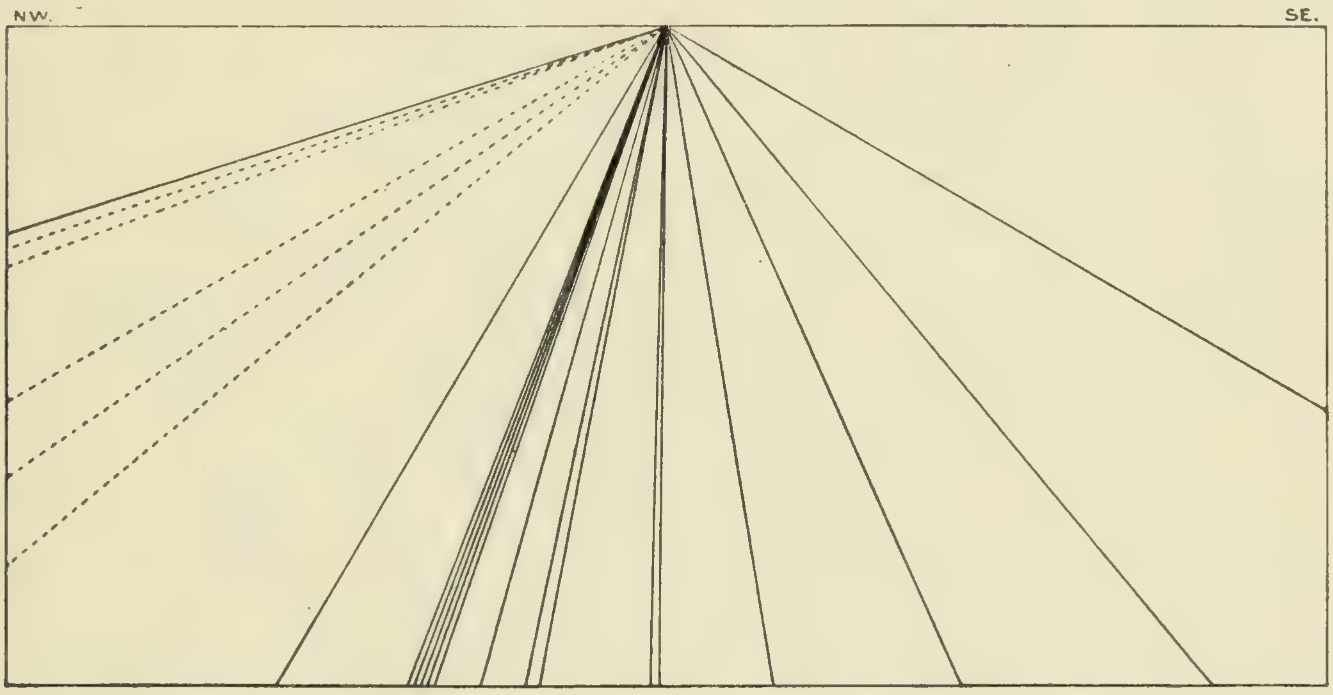


FIG. 94.—Tabulation of dip of principal NE.-SW. observed joints.

Nonpersistent joints.—Of even greater importance than the last-named class of joints are those which stop without a parallel joint to accommodate the strain. These generally stop at the junction with a joint of a different attitude, and in this case the strain is evidently taken up by the new fracture. This is one of the commonest features of jointing and is seen on both a small and a large scale. Occasionally it is possible to find a nonpersistent joint which terminates blindly in

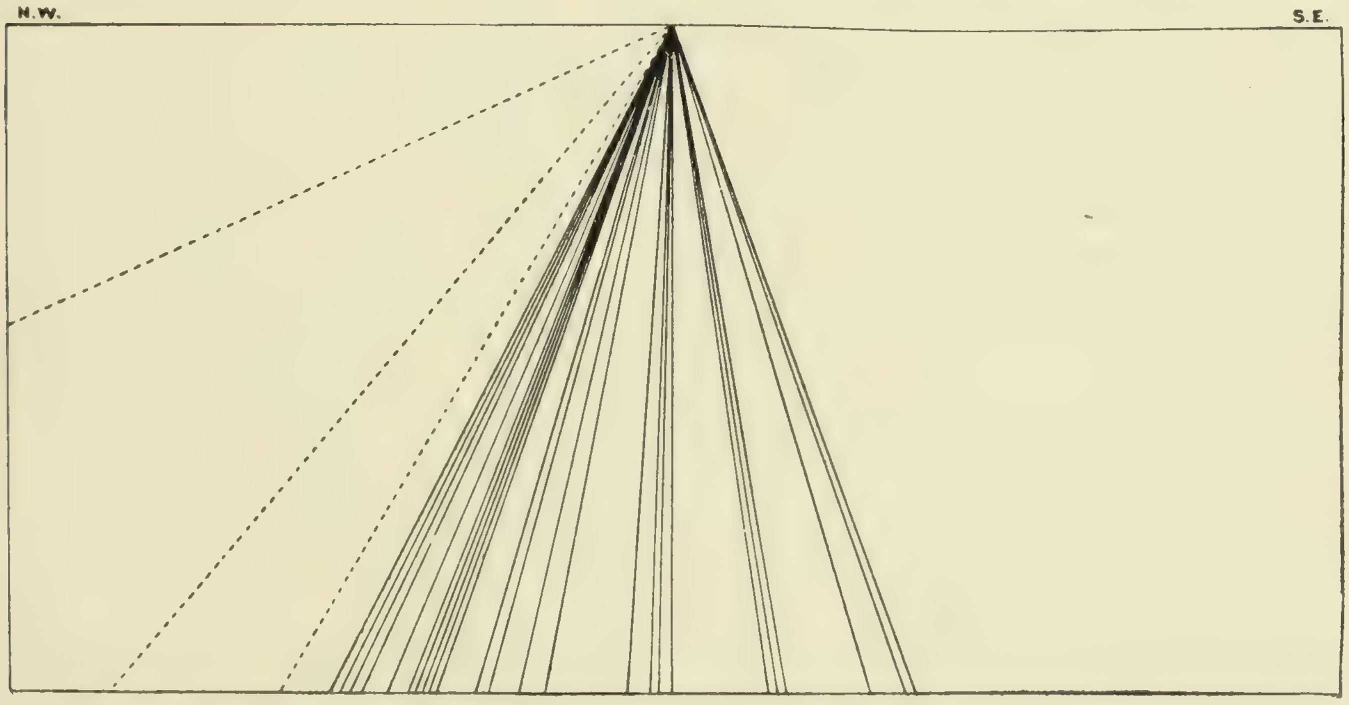


FIG. 95.—Tabulation of dip of principal NE.-SW. observed veins.

the rock, as far as the naked eye can perceive, and not in a transverse joint. In this case the strain which was accommodated in the joint crack has undoubtedly been taken up farther on in smaller fractures not visible to the eye (fig. 97).

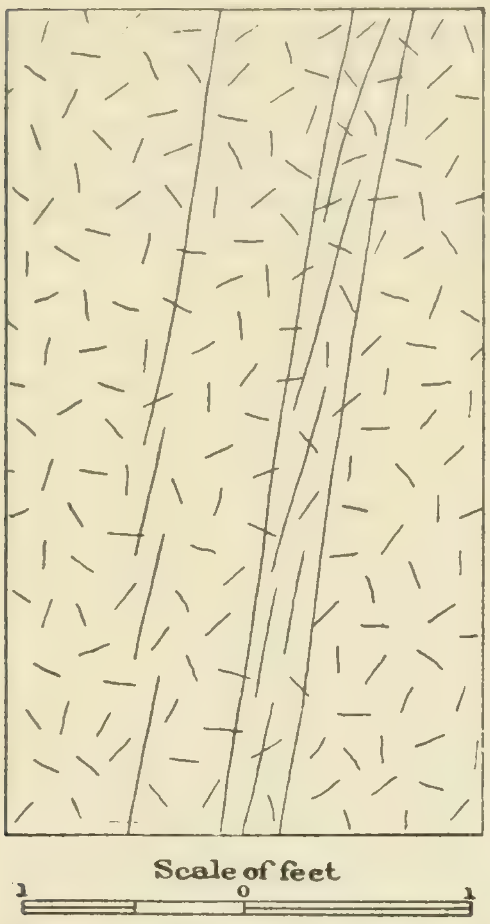


Fig. 96.—Sketch of joints in tonalite, head house of Mystery mine, showing imbrication.

Strain zones with concomiant oblique jointing.—A notable class of the nonpersistent joints is found within zones of special strain. Most of these observed zones follow the predominant east-northeast strike and steep northwesterly dip. Within the belts not only is there considerable jointing parallel with the chief planes of fracture, but oblique planes, confined to the strain zone, and evidently a manifestation of the same strains which produced the main set, are abundant. The oblique joints may belong to one or more sets, and thus may be parallel or intersecting. They also may be imbricating. They are nearly always nonpersistent, terminating with the limit of the main strain zone. Fig. 96 illustrates this special type of joints.

Relatively greater openness of jointing near the surface.—It is a matter of observation in the Monte Cristo district that the joints near the surface are much more open than those even 200 or 300 feet farther down. At the surface the rocks are seen to be traversed by great parallel cracks. As we go farther down the rocks become more compact, until in the greatest depths attainable in mine workings, which are approximately 500 feet from the surface in the Monte Cristo district, many of the seams are so close that they can hardly afford ready passage for solutions, and many become apparent only by disturbance of the rock, as in blasting.

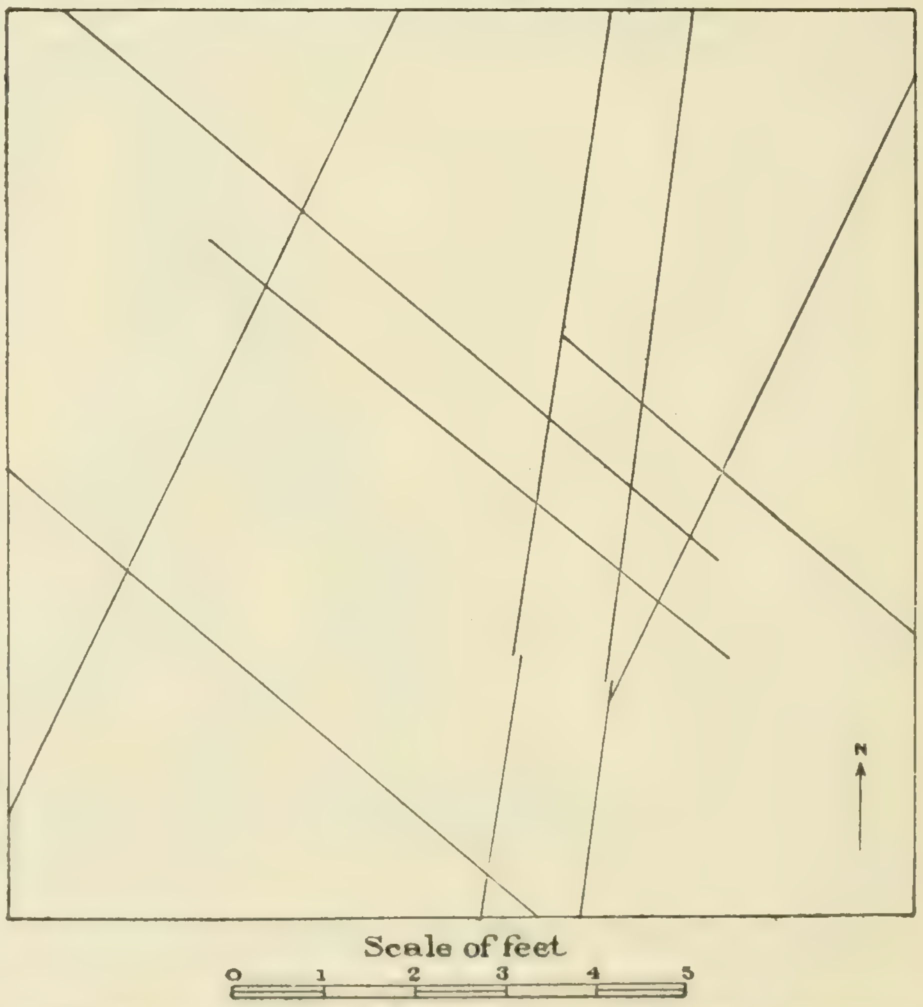


Fig. 97.—Sketch diagram of jointing in tonalite on horizontal surface to show imbrication and nonpersistence of joints, Glacier Creek.

It is theoretically admitted that the openings in rocks become less in amount as the distance from the surface is increased. This lessening may be attributed to the increasing pressure exerted by the superincumbent rocks, but where the difference is so great within a comparatively short distance from the surface it is probable that this cause is not chiefly influential. A most important and evident cause in this case is the straining which gravity exerts near the surface. Most of the rock surface is on the sides of very steep mountains, and therefore the surface zone of rocks is subjected to gravity strains against which it has no sufficient support below; hence landslides are frequent, and in nearly every case the rocks must at least yield and move somewhat to accommodate the strain. Another agency is probably also in part responsible for the opening of the joints. This is the surface water, which is especially abundant in the upper zones and is active chemically. The effect of these atmospheric waters, as is well known, is generally to abstract more material from the rock through which they percolate than they can give back in return. Unless this diminution is compensated by an increase of volume due to change of chemical condition there results a decided contraction of the rock. This has probably occurred in the Monte Cristo district.

STUDY OF MINOR COMPLICATIONS OF VEINS FORMED ALONG JOINTS.

The veins formed along joints naturally partake of all the complications of jointing, and have the further complication that they may pass irregularly from one joint to another. These variations will be only briefly summarized, since they require no detailed description, and the figures presented are sufficient in themselves.

Veins along zones of maximum chief jointing.—The zone of especially intense east-northeast jointing, above mentioned as extending from Goat Lake through the Monte Cristo district down Silver Creek, is also a zone of maximum mineralization, nearly all of the principal veins of the region being located in it.

Within the main zone of principal jointing the minor belts of maximum fracture, above described as leading to minor irregularities in the topography, constitute the chief veins. Upon such fracture zones, generally not many feet in thickness, are situated the most important ore deposits of the district, such as those at Goat Lake, those of the Pride, Mystery, and Golden Cord mines, those of the Louise tunnel, etc. (figs. 98 and 99).

Imbricating veins.—The imbrication of ore veinlets on a small scale is relatively quite as frequent as that of unmineralized fractures. On a large scale it has not been definitely observed, but on the lower level of the Monte Cristo mine the apparent breaking and overlapping of the separated ends of the main vein is possibly due to imbrication of the main fracture zone. This apparent break has been explained as a fault, but there is no adequate evidence to support the suggestion. There is another reasonable probability, namely, that this is a case where the mineralization has passed somewhat irregularly from one joint set to a near-by and parallel set. Exploration is needed to decide this question.

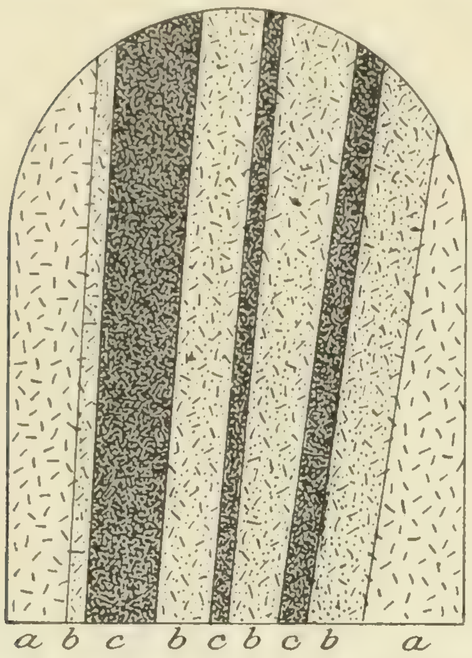


FIG. 98.—Sketch of O. and B. vein in earlier andesite, breast of lower tunnel. Scale, 1 inch = 7 feet. *a*, solid andesite wall rock; *b*, andesite, sparingly impregnated with sulphides; *c*, solid arsenopyrite.

Nonpersistent veins.—Veins that apparently terminate upon running into other veins which have a different attitude are among the most common special features of ore deposition, and this principle is of great importance from a commercial standpoint. The most striking examples on a large scale are found in the mines of the Goat Lake district, and the accompanying sections give some examples of its occurrence elsewhere (figs. 100 and 101).

It is also very common to find a vein gradually wedging out until it ends in a completely unmineralized fracture or one so slightly mineralized that it yields nothing which can be classed as ore. It will be noted that this type of nonpersistent veins does not correspond exactly to the nonpersistent joints, the joints being in this case generally persistent, while the veins represent the results of special processes acting selectively along certain portions.

Strain zones forming the chief mineral lead, with concomitant oblique veins.—This type of veins is dependent upon the special type of jointing previously described. Many of the chief veins or mineral leads are characterized by the presence of oblique veins which have formed along joints whose extension is generally limited to the chief zone of mineralization. These oblique veins are sometimes few; sometimes they are more abundant and are parallel. In the larger veins they are apt to deviate at a moderate angle from one another and from the chief attitude of the main vein or lead. Thus in the case of the predominant set of veins these oblique joints inclose horizontal or pitching prisms of rock of rhomboidal cross section as seen in a vertical diagram (see Pl. LXXXII, *A*). A vein may form upon any of these intersecting joints, but preferably it appears upon the lower one of each conjugated set. When the mineralization

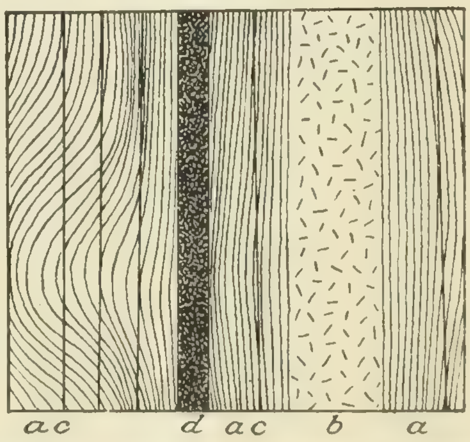


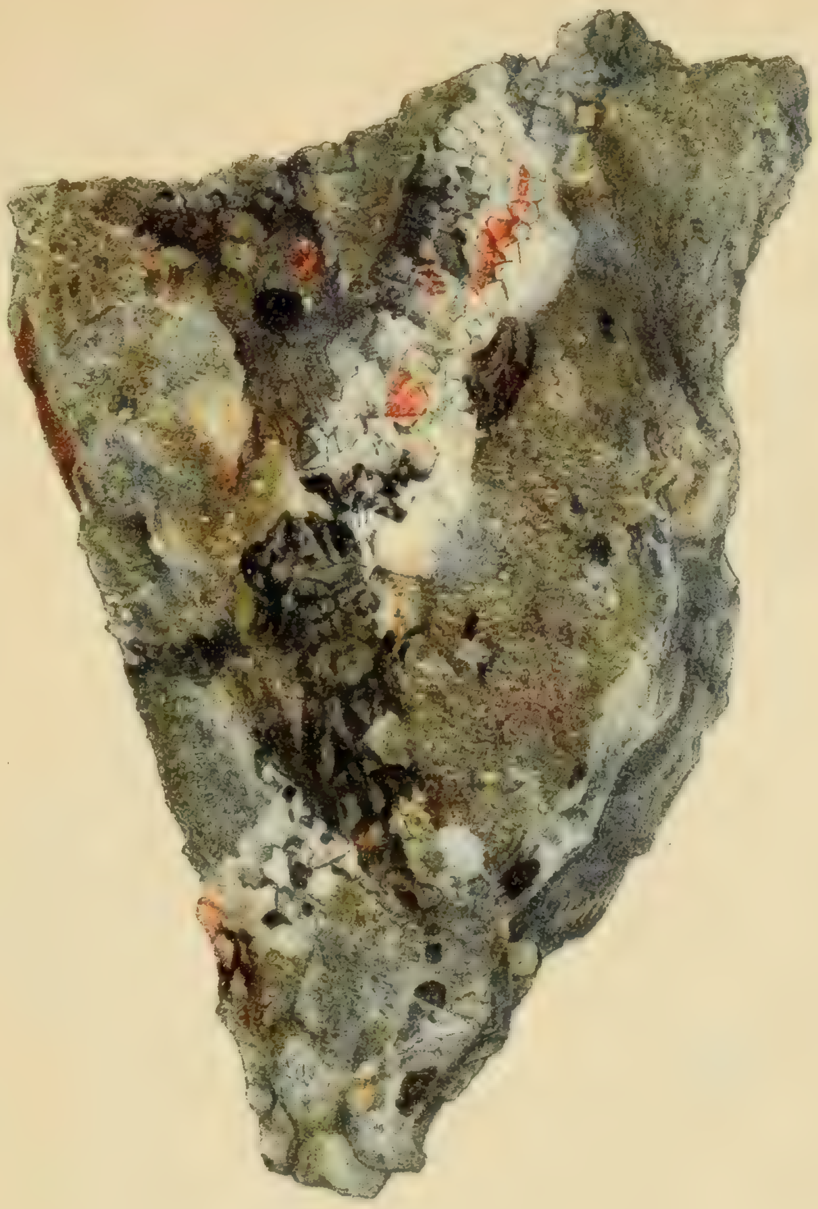
FIG. 99.—Sketch of vertical outcrop of arsenopyrite vein, Rainy mine, south side of Glacier Creek. Scale, 1 inch = 6 feet. *a*, black schist, with quartz veinlets; *b*, tonalite dike; *c*, fractures; *d*, arsenopyrite vein.

PLATE LXXXII

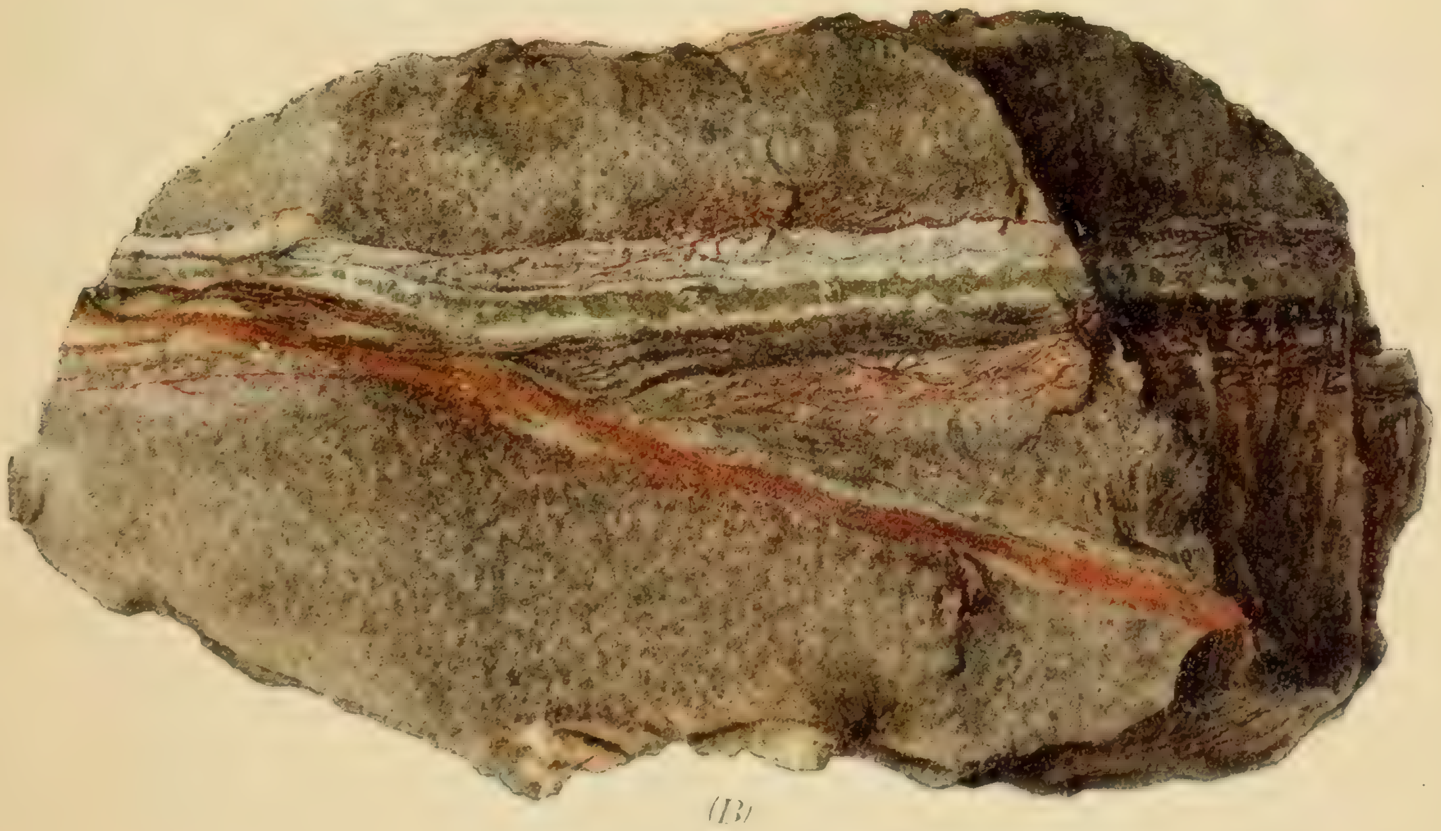
PLATE LXXXII.

A. Specimen of tonalite from mountain east of Glacier Creek, showing mineralization of intersecting joints.

B. Specimen of ore from Foggy Tunnel, Goat Lake, showing relative age of sulphides. *a*, arsenopyrite; *b*, blende; *c*, quartz and calcite; *d*, realgar.



(A)



(B)

JULIUS BIEN & CO. N.Y.

ROCK SPECIMENS FROM MONTE CRISTO DISTRICT

(A) SPECIMEN SHOWING ORE DEPOSITION ALONG INTERSECTING JOINTS

(B) SPECIMEN SHOWING SUCCESSIVE DEPOSITION OF DIFFERENT SULPHIDES

is sufficiently great, it extends preferably from the joints into the rhomboid rather than away from it, probably because the rock within has been more crushed than the rest. Thus complete mineralization of the rhomboidal prism is attained and a body of ore formed which in a vertical section has the form of a very large flattened rhomboid or roughly of a lens (fig. 102). In horizontal section also these ore bodies have an extremely flattened rhomboidal shape, but this is probably in general due to the fact that the prisms do not lie horizontal, but at an angle to

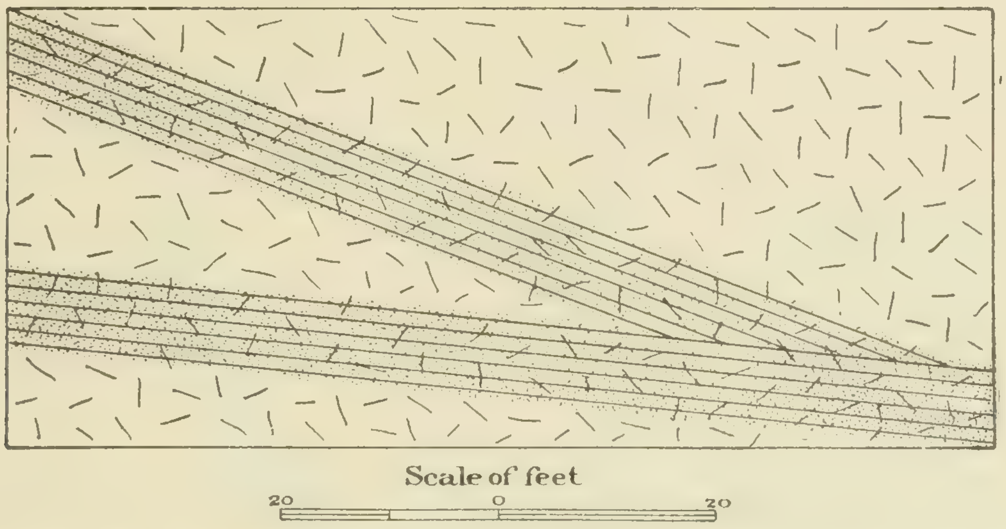


FIG. 100.—Horizontal plan of mineralized joint zones in tonalite on mountain northeast of Glacier Creek. Shading shows impregnation with sulphides.

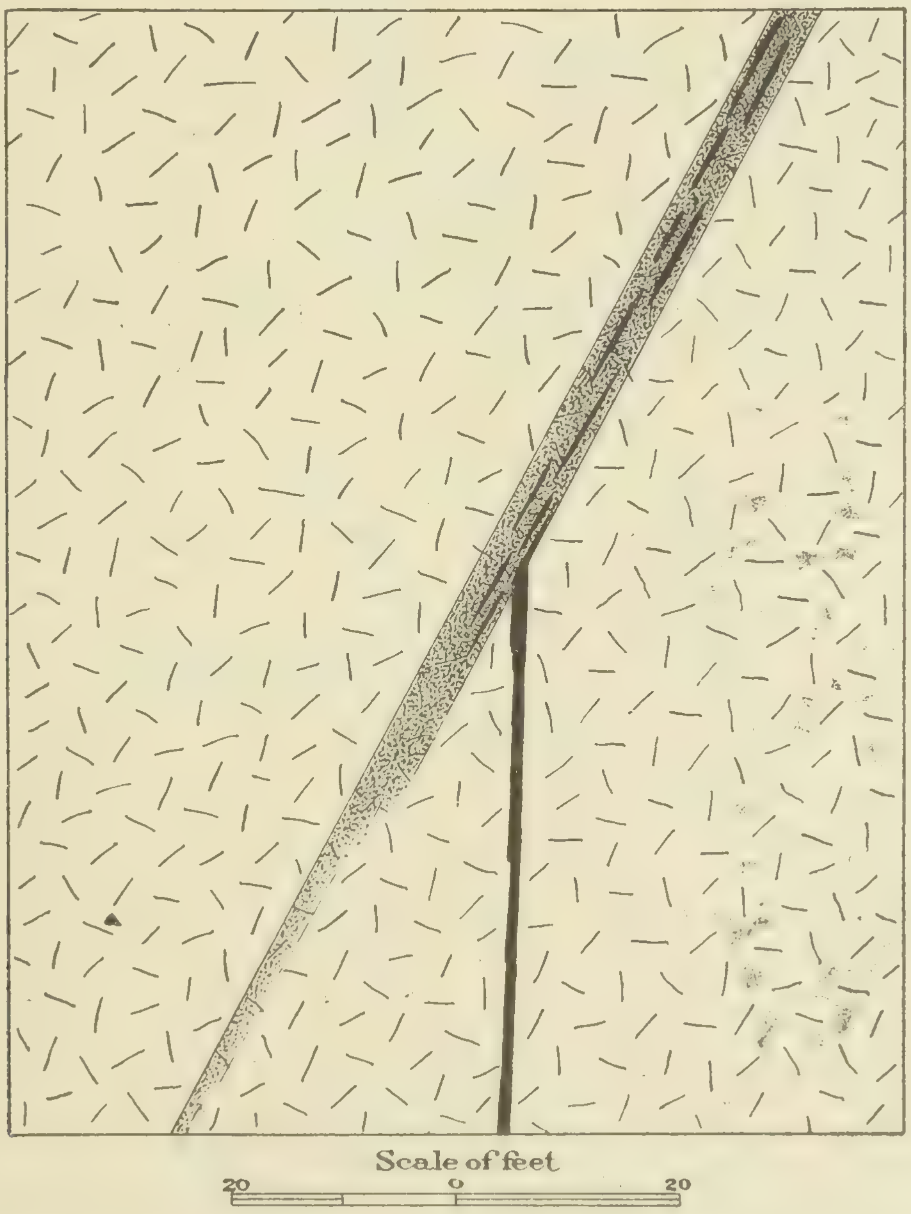


FIG. 101.—Vertical sketch section in tonalite of canyon wall, mountain northeast of Glacier Creek, showing sulphide vein passing from one joint to another.

the horizontal, so that the horizontal section is really a very oblique cross section (fig. 103). The true form of the ore body, therefore, is to be conceived as this inclined prism with a flattened rhomboidal cross section. The pitch of the prism, which is also the pitch of the ore shoot, is variable, and the length of the prism is also variable, being not indefinitely continuous, but terminated by the cessation of conditions favorable for thorough mineralization. These conditions

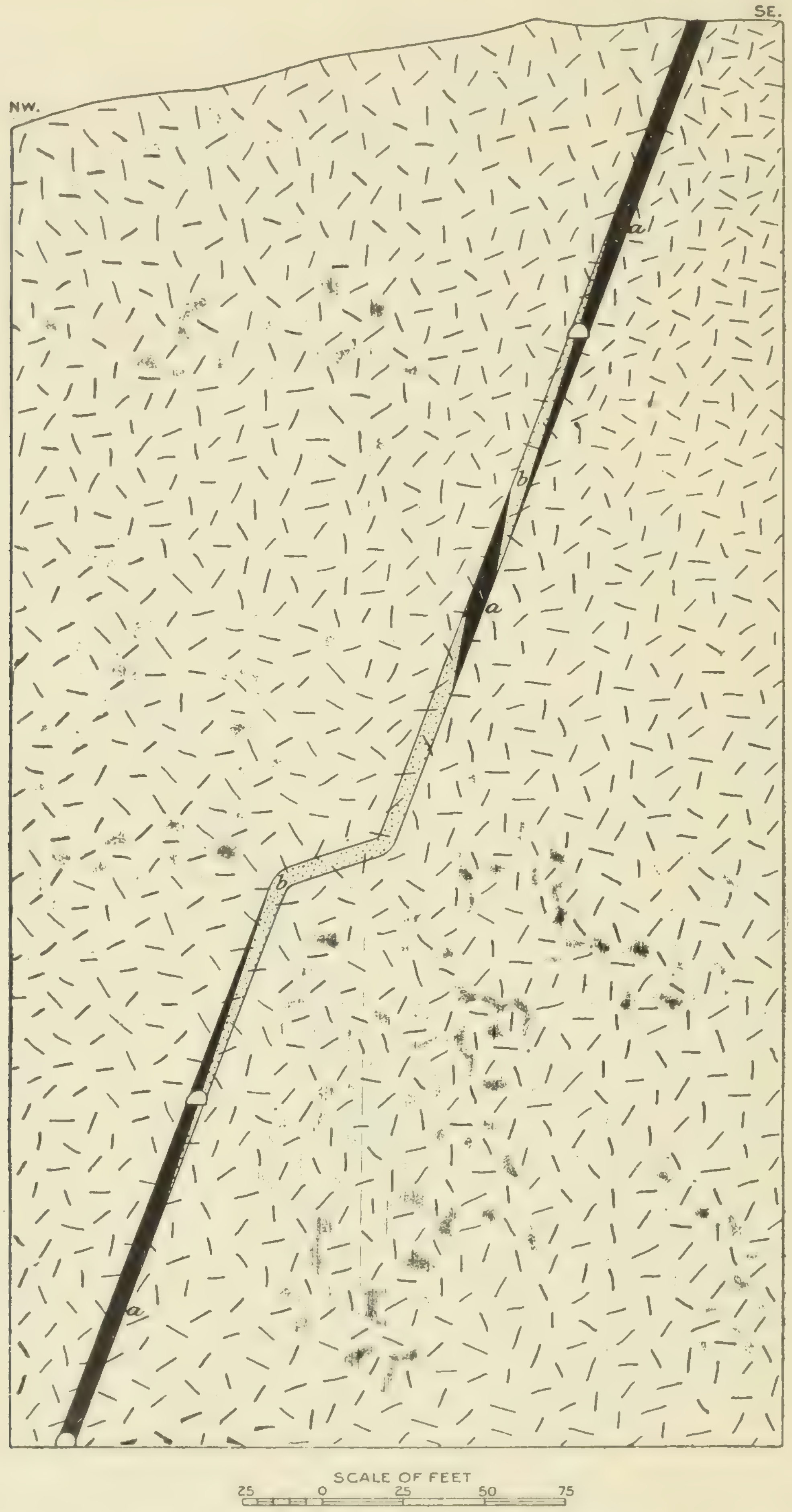


FIG. 102.—Rough vertical cross section of Mystery-Pride vein, showing ore lenses. *a a a*, nearly solid sulphide bodies; *b b*, barren vein, chiefly decomposed country rock (tonalite). Section is taken from eastern end of third level of Mystery, vertically upward through Pride winze and Discovery tunnel. Fractures in tonalite omitted.

are somewhat complicated and will not be discussed here, but among them may be enumerated distance from the surface and connection with transverse joints which act as feeders.

Vein irregularities consequent on successive selection of different joints.—It is a fairly reliable statement that in this district the straightest veins are the richest. The reason for this is that the straight veins mark a fracture zone so important as to control the circulation and not permit it to be tapped and drawn off by some intersecting fracture. Very many of the lesser veins, however, have formed where there has been no persistent master zone of jointing. The result is that while the vein itself may be often traced continuously by unmistakable characteristics, yet it shifts its course from one joint to another, and so becomes zigzag. The accompanying figure shows an instance of this very common type of lesser veins (fig. 104).

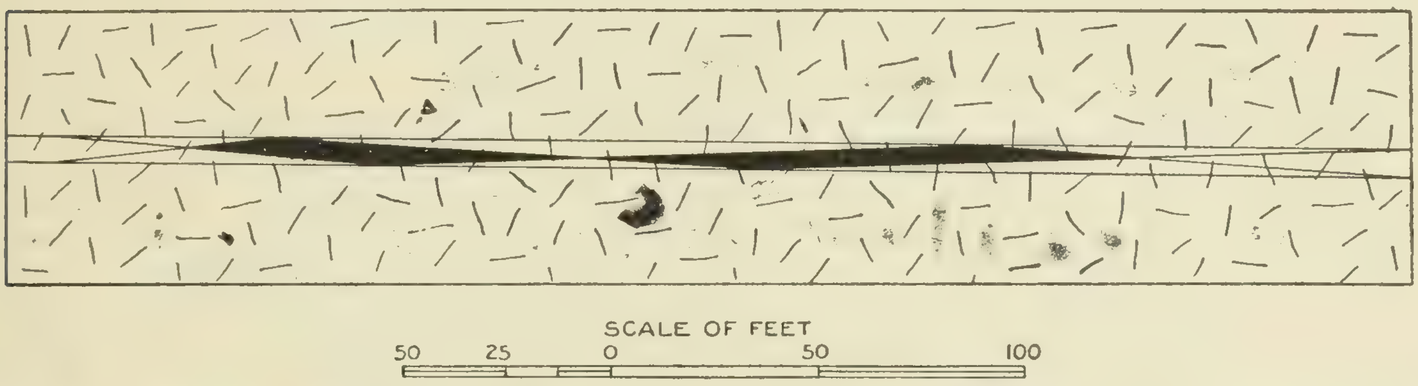


FIG. 103.—Horizontal sketch plan, showing ore lenses on main vein, as exposed in big stopes above third level, Mystery mine. Ores massive arsenopyrite, with a little blende and chalcopyrite.

Complication of veins near the surface.—Veins when near the surface are rarely simply straight and persistent, even where they become so in depth (see fig. 105). This is well illustrated in the case of the great vein along which the Mystery and Pride mines, and probably the Golden Cord, are situated. The vein in the Golden Cord and Mystery mines is exceedingly straight and persistent, but in the upper workings of the Pride becomes so irregular that the miners could find no definite rule for the position of the ore bodies and were forced to explore somewhat at haphazard. In the deeper

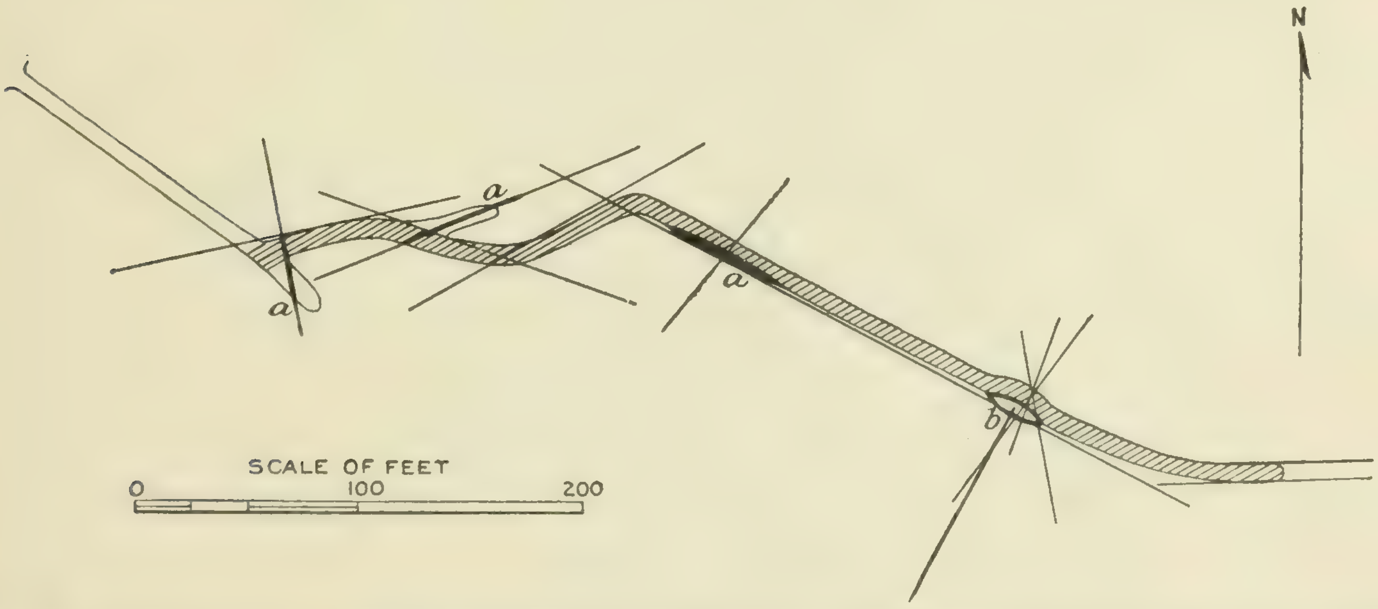


FIG. 104.—Rough plan of Seventy-six main tunnel, showing lead passing from one joint to another.

workings before mentioned the ores have formed entirely along a master zone of fracturing having the predominant east-northeast strike and steep northwesterly dip. This joint system is traversed by another of the principal subordinate systems of the region, which has approximately the same strike but a comparatively flat dip, averaging perhaps 30°. In these deep workings, however, ore has not made along the flat joints away from the master zone to any extent, evidently because the joints are so close as not to permit of any considerable circulation of mineralizing solutions. In the upper workings, however, as the surface is approached the ore begins to make freely along these flatter joints, so that a series of steps or rolls is produced by the vein changing from the steep-dipping set to the flat-lying set repeatedly. Moreover, as the surface is neared the ore makes not only

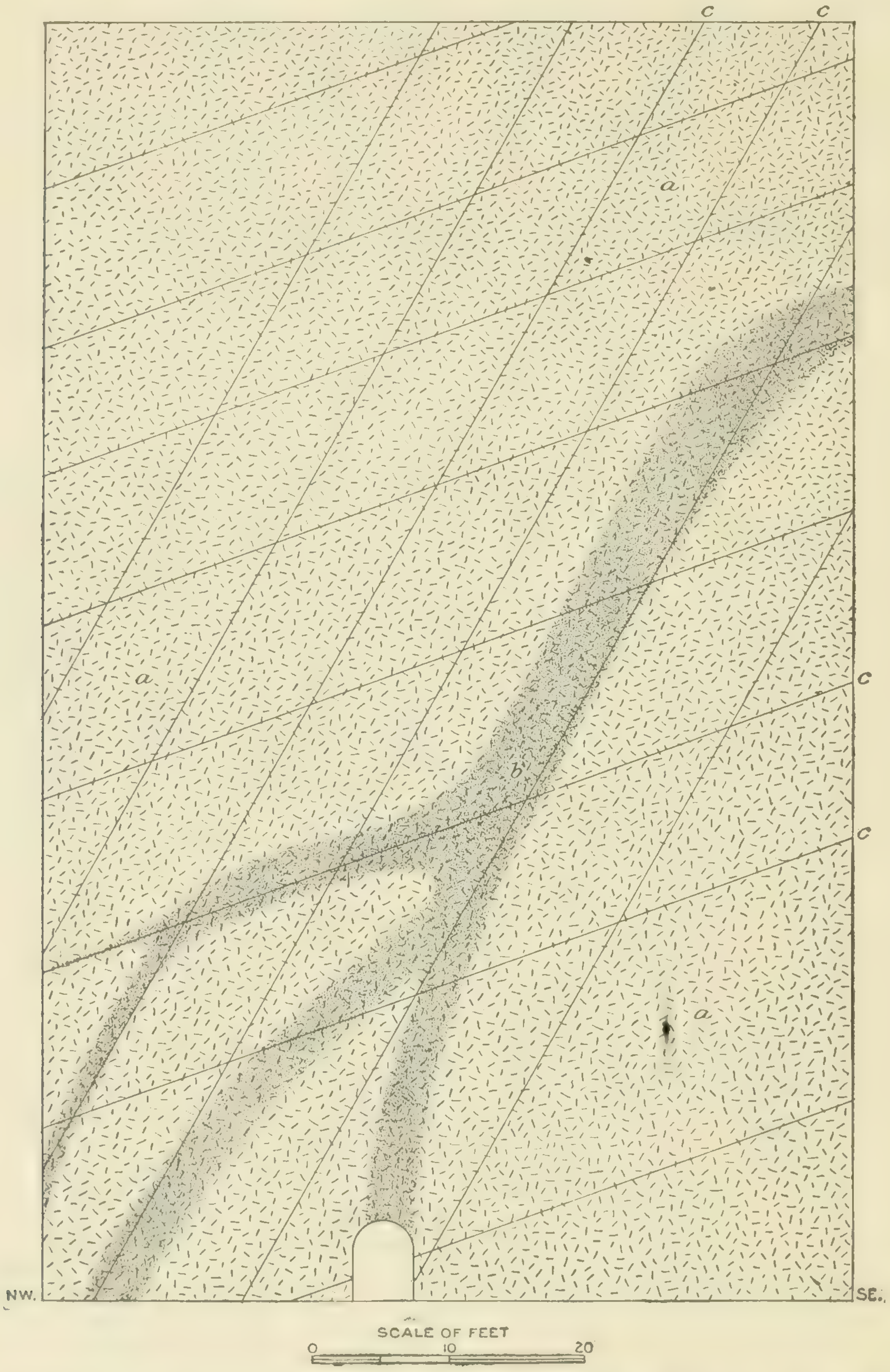


FIG. 105.—Diagrammatic sketch of cliff above upper Seventy-six tunnel to show irregularities of veins near the surface. *a*, andesite; *b*, andesite impregnated with sulphides, which sometimes become solid; *c c*, chief "lead."

along these two joint systems, but also along nearly all of the several other joint systems in the rock which have been described, so that very irregular and puzzling distribution of the ores results (see fig. 106). In one case where mineralization had occurred irregularly along a set of intersecting and diverging joints, an old miner graphically compared the ore body to a "squashed" spider.

Not only is the complication of the veins in this respect evidently dependent upon proximity to the surface, but it is also plainly related to the abundance of the joints near the surface, as above described. The opening of the joints has afforded circulation along nearly all the systems for mineralizing solutions, whereas in depth the joints are so close that the solutions have been chiefly confined to the master zone of fracturing. This is shown by the finding in the surface zone of many small joint fissures filled with quartz and calcite, which is a phenomenon very rarely observed in the lower workings (fig. 107).

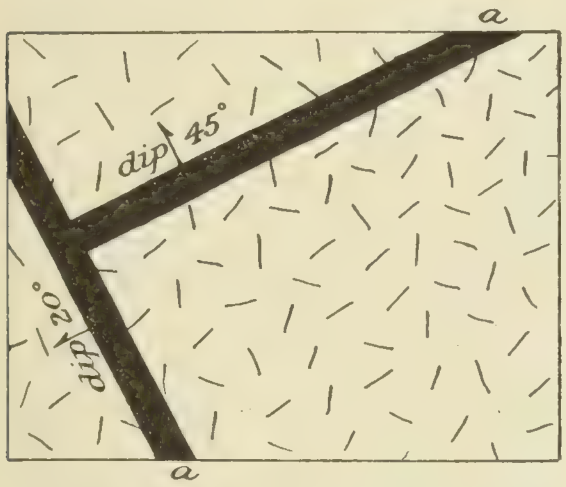


FIG. 106.—Rough horizontal sketch plan of veins in old surface workings, Pride mine, to show irregularity of veins near surface. *a a*, solid bodies of sulphide ore rich in galena and blende. Country rock, tonalite. Scale, 1 inch = about 30 feet.

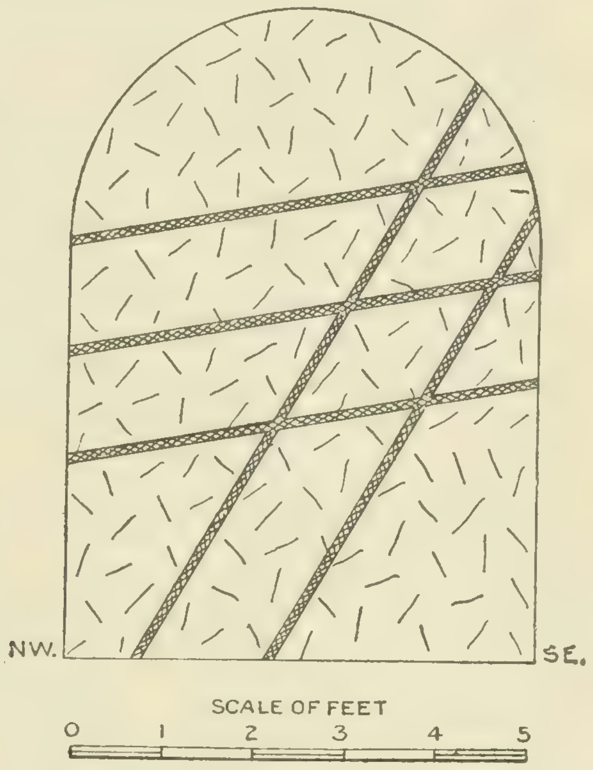


FIG. 107.—Sketch of breast of tunnel in upper surface workings, Pride mine, showing intersecting joints belonging to the principal systems, filled with veinlets of calcite and quartz, with sparse sulphides.

LEAD AND POCKET, OR ORE BODY, AS PARTS OF THE VEIN.

In the Monte Cristo district a vein may be continuous and easily followed without being continuously or equably mineralized. The barren portions of the vein are generally slightly impregnated with sulphides, or they may be almost entirely without metallic minerals, but they are quite distinct from the wall rock by reason of the decomposition and generally the consequent staining with iron oxide. At intervals this barren portion of the vein becomes richer in metallic sulphides and the mineralization may increase so as to form an important ore body, capable of being mined with profit. Following these facts and conforming to and fixing definitely the miner's nomenclature, these barren reaches, which in some veins constitute the greater portion, in others the lesser, we may call *leads*, while the accumulations of sulphides sufficient to be worked or to give promise of being worked we may call *pockets* or *ore bodies.* According to this definition, the *lead* and the *ore body* are both parts of the *vein.*

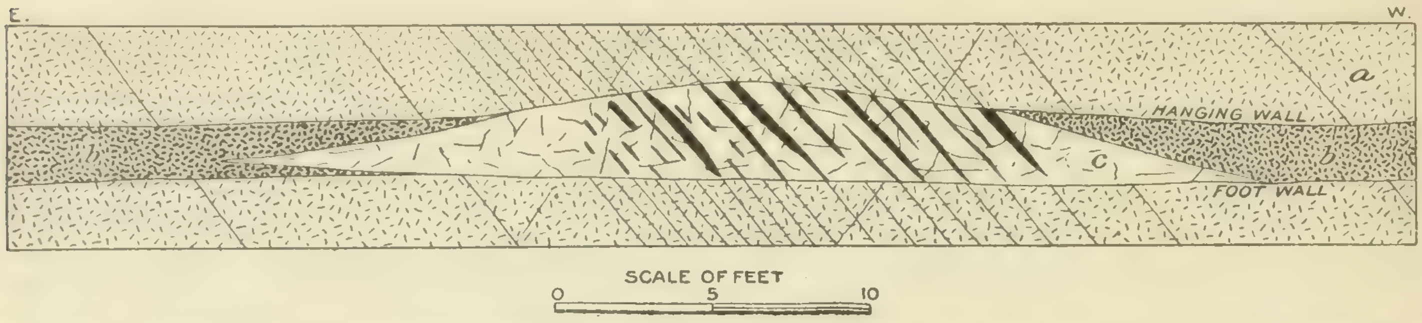


Fig. 108.—Longitudinal vertical section of vein in main Seventy-six tunnel, as sketched from drift wall, to show ore deposition at intersection of fractures. *a*, fractured andesite; *b*, barren " lead," chiefly decomposed andesite slightly mineralized; *c*, white quartz lens; *d*, streaks of solid sulphide in quartz. About 500 feet (both horizontally and vertically) from surface.

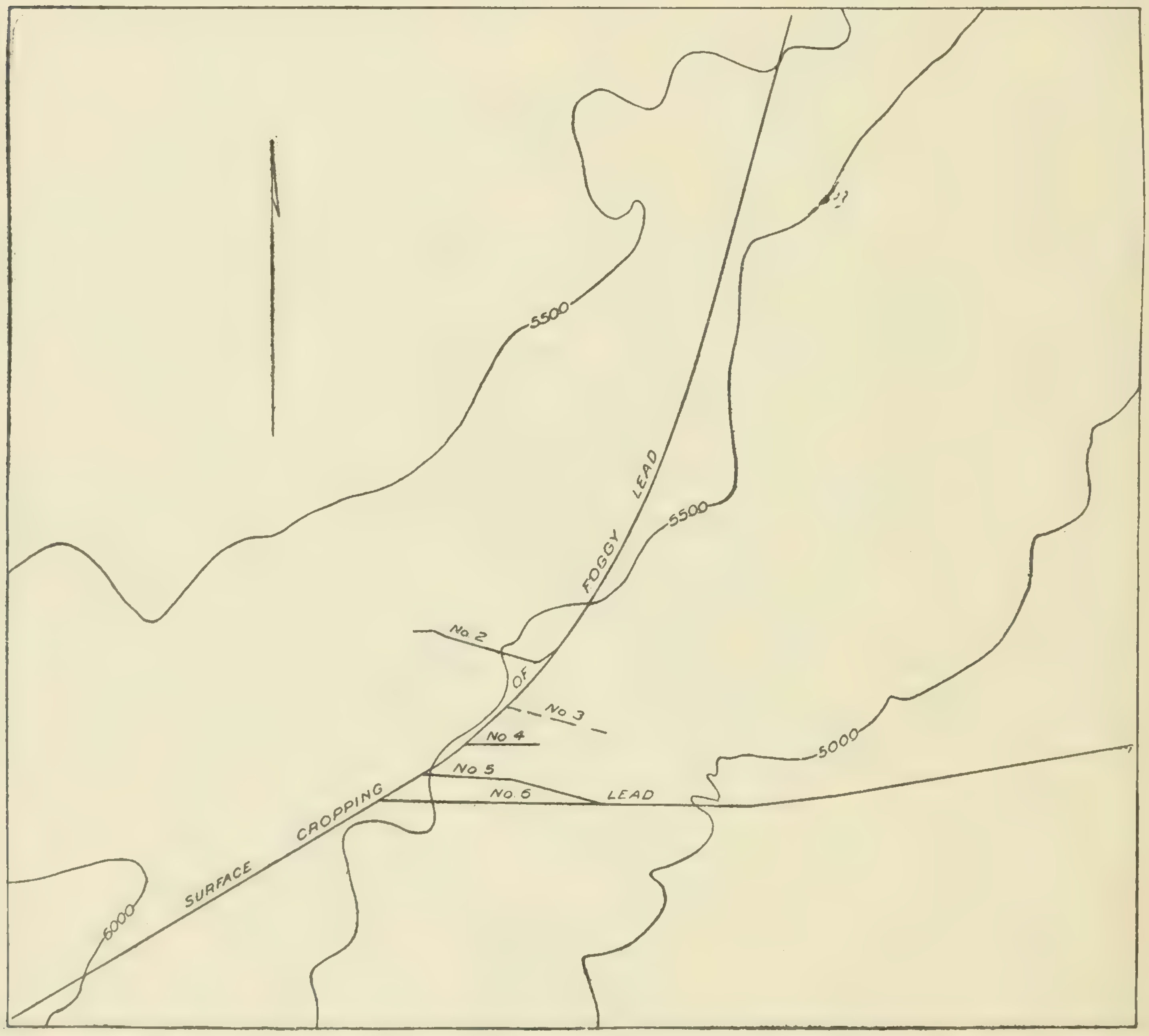


Fig. 109.—Map showing cropping of Foggy and subordinate leads near Osceola Pass, south of Goat Lake. The leads are in general marked by zones of fracturing, decomposition, and staining. The ore bodies occur chiefly at the intersection of the leads.

POSITION OF POCKETS AND ORE BODIES.

Influence of intersecting joints.—The intersection of transverse joints with the main vein has evidently in many cases determined the formation of a pocket or ore body, which may form partly in the main vein and partly along the transverse fracture (fig. 108). In this way branching veins arise, which, when followed some little distance from the main lead, give place to a barren fracture.

On a larger scale more important bodies are sometimes located at the intersection of different minor strain zones. The best example of this is in the Goat Lake district, where the principal ore bodies have thus been determined. While the minor ore bodies determined by cross fractures in the lesser veins are generally not many yards in length, in the Goat Lake district the ore bodies form distinct shoots, running along the intersection of two zones and traceable for several hundred feet downward, pitching at a steep angle (fig. 109).

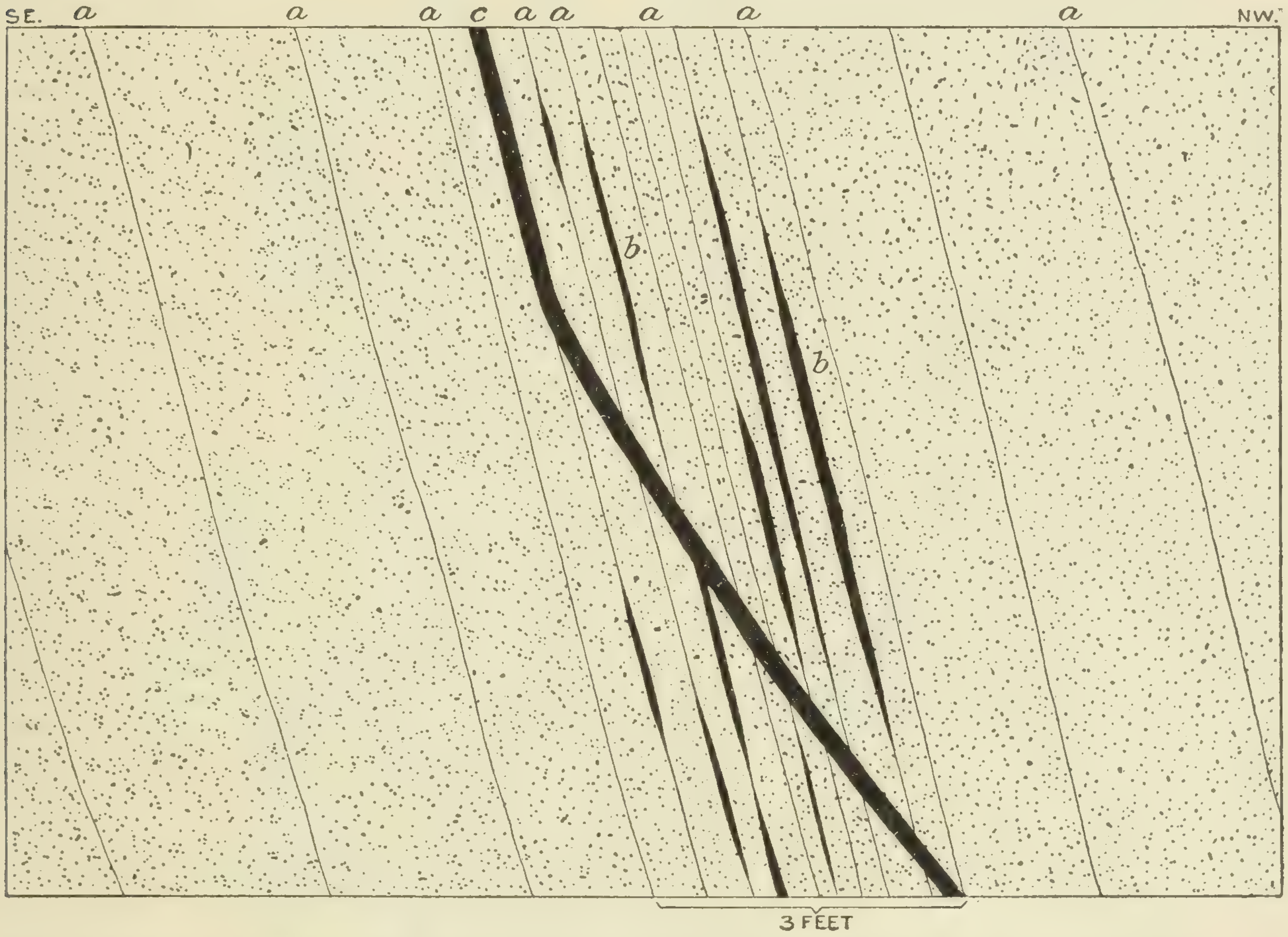


FIG. 110.—Sketch of Seattle lode, Red Gulch, to show the comparatively rich precipitation along oblique fractures in joint zones. *a a*, joints; *b b*, small black sulphide streaks, chiefly impregnations; *c*, quartz vein, with sulphides. Rock, massive quartzite slate.

Within a minor strain zone, where the parallel joints or fractures are closely set together, determining a vein, there are frequently oblique fractures. These comparatively rare diagonal joints appear to afford greater opportunities for mineralization than the others, for frequently they show a continuous deposit of ore, while the others have very little (figs. 110 and 111).

In each of the three minor cases above mentioned—the formation of small ore bodies and pockets at the intersection of transverse fractures with veins, the formation of important ore shoots at the intersection of two minor strain zones, and the relatively greater mineralization of oblique fractures across strain zones as compared with the main systems of fractures—the principle is the same. Evidently the intersection of one fracture or set of fractures with another is a more favorable place for ore deposition than any other point along either of the fractures.

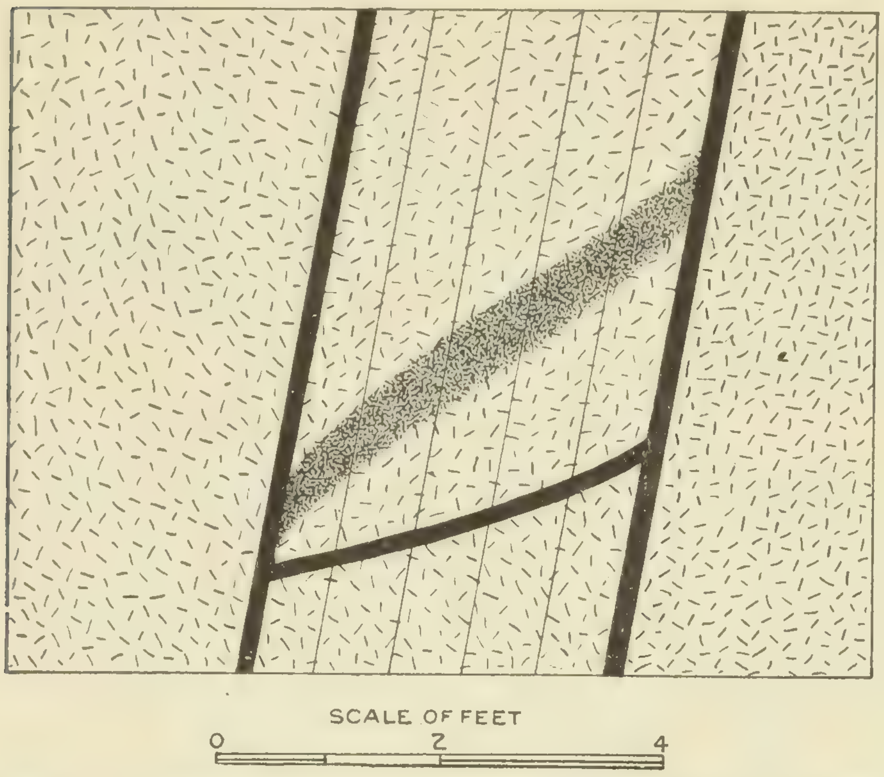


Fig. 111.—Sketch of vein in tunnel 200 feet west of Olive May, to show precipitation along oblique fractures in joint zones. Ores, arsenopyrite with some chalcopyrite, pyrite, and blende; country rock and vein rock, highly silicified andesite.

Ore lenses.—In the most important mines of the district, the Mystery and the Pride, the extensive workings have shown that the ore along this rich vein has formed in very flat lenses. These average between 50 and 250 feet in diameter, and run in thickness as high as 6 feet (see figs. 102 and 112). They are generally bounded by minor oblique joints included within the general strain zone, these joints often being at a very slight angle with the walls of the vein and of different systems, which meet and intersect within the strain zone itself. Thus the lenses themselves generally diverge at a very slight angle from the walls of the vein. An ore lens which begins on the foot wall of the vein when followed downward often wedges out against the hanging wall. In this case, at the upper end of the lens, there is a barren portion of the vein between the ore and the hanging wall. At the lower end of the lens there is a similar barren portion between the ore and the foot wall. When a lens thus wedges out and disappears against the hanging wall, for example, the barren portion is cut through by the miner to the foot wall, where the beginning of another lens is generally found extending downward and thus forming a sort of imbricating or overlapping continuation of the other lens, although without any actual communication with it. This is the most common

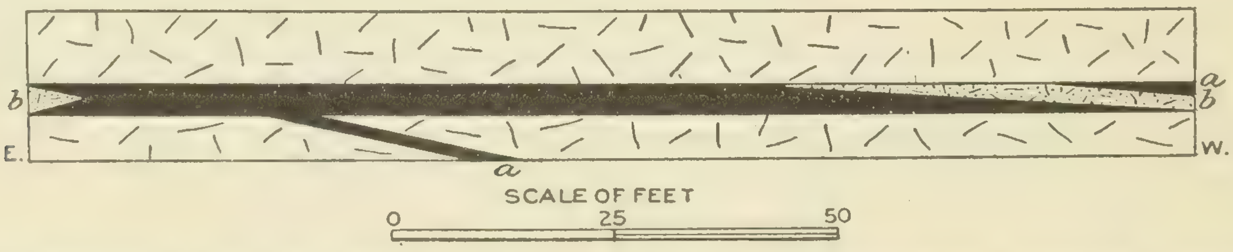


Fig. 112.—Horizontal plan of stopes above Discovery tunnel, Pride mine, showing imbricating lenses, branching vein, and dovetail termination of ore body. *a a a*, bodies of solid sulphide ore; *b b* barren vein material (more or less decomposed tonalite). Country rock, tonalite. Fractures in tonalite omitted.

relation of the lenses. Occasionally, however, when the bottom of a lens is determined by the converging of the two slightly diverged joints by which it is bounded, the ore is found farther down between the same joints, where they open out again after their intersection. The two lenses thus have an hour-glass form, constricted to almost nothing at the intersection of the joints and opening out to several feet, generally the whole width of the strain zone, above and below (fig. 113).

In the upper workings of the Pride is a modification of the ore lens which is typical of some of the other less-developed veins of the district. In the lower workings, which have just been described, the lenses are all steeply dipping and all lie within the straight unbroken strain zone dipping 60° to 70°. Near the surface, however, there occurs a series of rolls, the steep vein turning and running at a flat angle for a number of feet and then resuming its steep attitude. This may occur a number of times before the vein reaches the surface. Upon these flat benches the ore is more likely to occur than along the steep portions of the vein, and forms also here rough lenses.

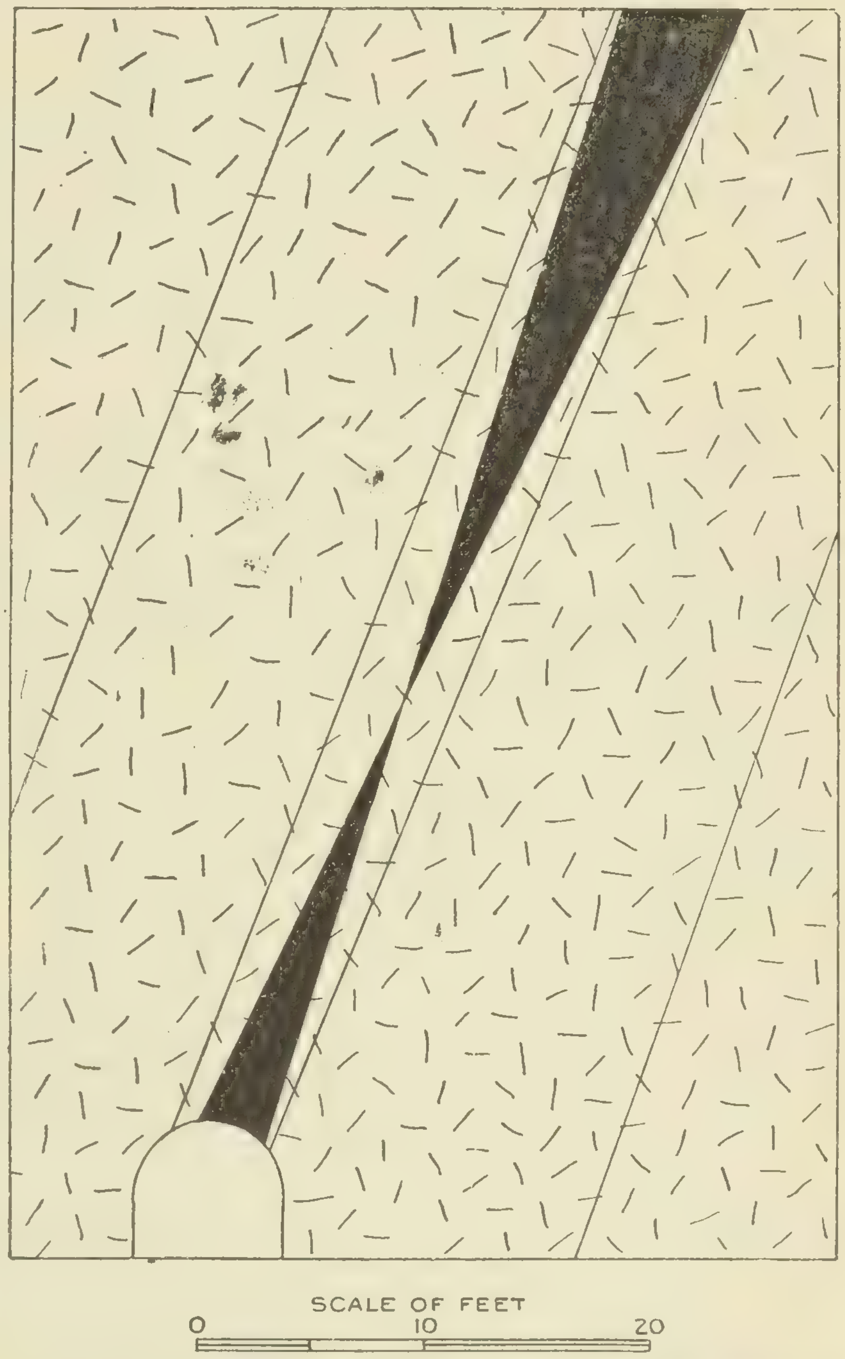


Fig. 113.—Ore bodies in Mystery mine, as shown in stopes above third level under Glacier Gulch, showing hour-glass connection of lenses. Ores, solid arsenopyrite, with a little blende. Country rock, tonalite.

A favorite theory to account for the formation of ore lenses along veins is that after a rock has been pierced by a wavy fracture there is differential movement on the two sides, so that two convex surfaces are brought together, leaving the concave surfaces inclosing lenticular openings. In these openings the ore is supposed to form. This theory is only mentioned in this connection to anticipate and deny any reference of the Monte Cristo lenses to this cause. In the Monte Cristo district in general the fractures are straight. There has been no movement of importance along them, and the ores have not been deposited in cavities or openings, but have replaced the tonalite little by little.

The actual explanation of the ore lenses is evident after a study of some of the successive stages of their formation. Along strain zones the oblique concomitant veins inclose prisms of flat rhomboidal cross section, certain of which have borne more strain than others that lie close by or between. The physical explanation of this can not be undertaken here, but the substantiation of the statement lies in the many fractures which have been observed in these strained prisms as compared with the others. When this is understood and granted—that along the zone of strain portions of the rock of rhomboidal cross section have naturally been more crushed and seamed than adjacent portions—the formation of the ore lens is clear; and, indeed, the various stages of this formation have been observed in the field, obviating the necessity of recourse to theory. The ore-bearing solutions, following naturally the main strain zone, have found their easiest channels in these crushed portions; so we often find such lenses in a stage where they are still chiefly rock, but traversed by many small seams of sulphides. The precipitation of the sulphides within these lenses themselves first takes place by preference at the intersection of the principal fractures which bound the prism; secondly, at the intersection of the minor fractures within the prism. By a growth of this process the sulphides spread from fracture to fracture until they meet, and finally, replacing little by little the country rock (which, in the case of the Mystery and Pride mines, is tonalite), they form a consolidated ore body, generally not strictly rhomboidal in cross section, for the mineralization has rounded the corners of the rhomb and made the cross section lenticular. Such an ore lens generally has as its walls tonalite, which is remarkably little altered and may indeed be quite hard.

The flat-dipping lenses which occur along the rolls of the vein within a certain distance from the surface have a nearly identical, though somewhat different explanation. In the deeper workings, as has just been explained, the lenses are bounded by concomitant oblique fractures within the main strain zone. Within the surface belt of rocks the flat lenses lying on the rolls of the vein are also bounded by oblique fractures, but these fractures, instead of being as before, are the intersecting joints of two different sets, one being that of the main strain zone below, while the other is an independent set having the same strike, but dipping at a much less angle; for while the main set, as before stated, has a northwest dip of 65° or 70°, this less important system has a northwest dip of 25° or 30°. Hence when the vein is deflected from the steeply dipping set to the flatter fractures, and a flat roll results, the vein only straightens itself up again when it seeks anew the steeply dipping set. Upon such a roll a flat ore lens will be bounded above and below by the fractures of the flat-dipping set, laterally by the main fractures (figs. 114, 115, and 126.)

Where the vein takes these rolls in the surface belt of rocks the local deflection from the main set to the flatter-lying set is evidence that the fractures of the flat set at this point were important and open. This openness of the subordinate joint systems in the surface belt has already been described and explained as dependent upon causes resulting from

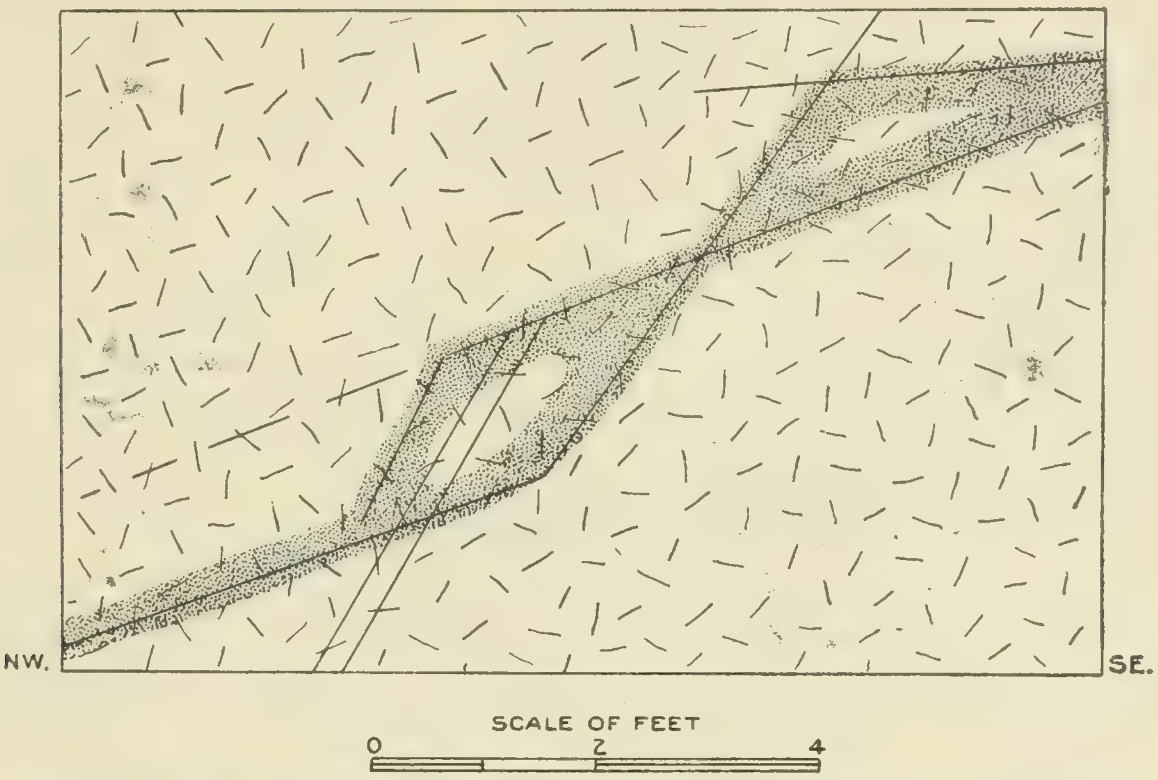


Fig. 114.—Sketch of tonalite at entrance of Mystery No. 1 tunnel, showing visible joints and mineralization. Mineralization shown by shading. This illustrates a stage in the development of ore lenses. Note nonpersistence of visible joints.

its proximity to the surface. When, on this account, the course of the main channel of circulation was once determined as passing in steps from the steep-dipping fractures to the flat ones, the flatter reaches

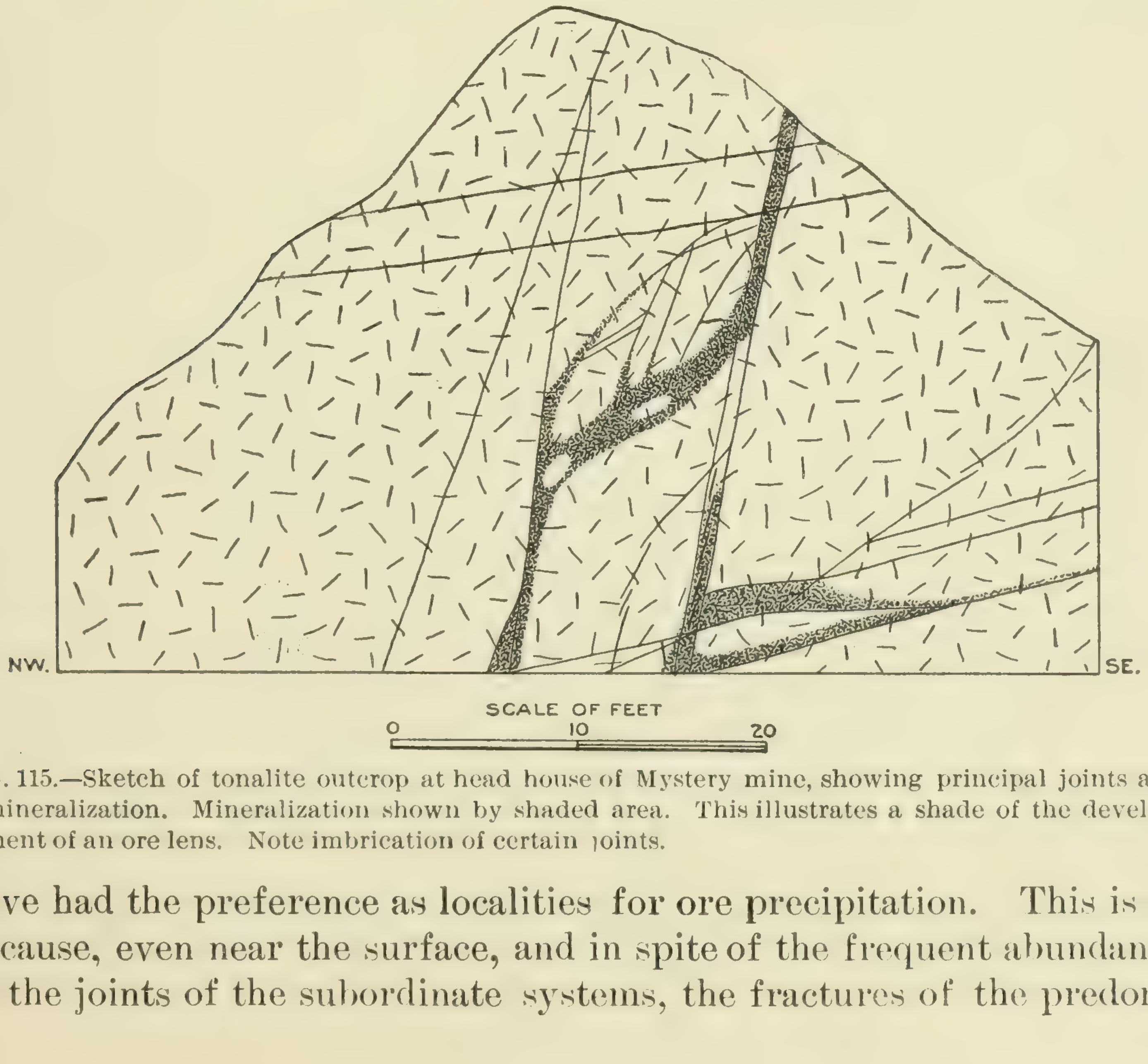


Fig. 115.—Sketch of tonalite outcrop at head house of Mystery mine, showing principal joints and mineralization. Mineralization shown by shaded area. This illustrates a shade of the development of an ore lens. Note imbrication of certain joints.

have had the preference as localities for ore precipitation. This is so because, even near the surface, and in spite of the frequent abundance of the joints of the subordinate systems, the fractures of the predom inating system, taken altogether, still remain the most important. Therefore the flat reaches of the main circulation channel intersect many cross fractures belonging to the predominant set, while the steep reaches intersect fractures of the subordinate set, which, on the whole, are less important. Hence the amount of solutions meeting on the flat reaches is greater than that on the steep portions, and consequently the precipitation by metalliferous sulphides is greater, determining the greater thickness of the resultant ore body on the flat rolls as compared with the steep portions.

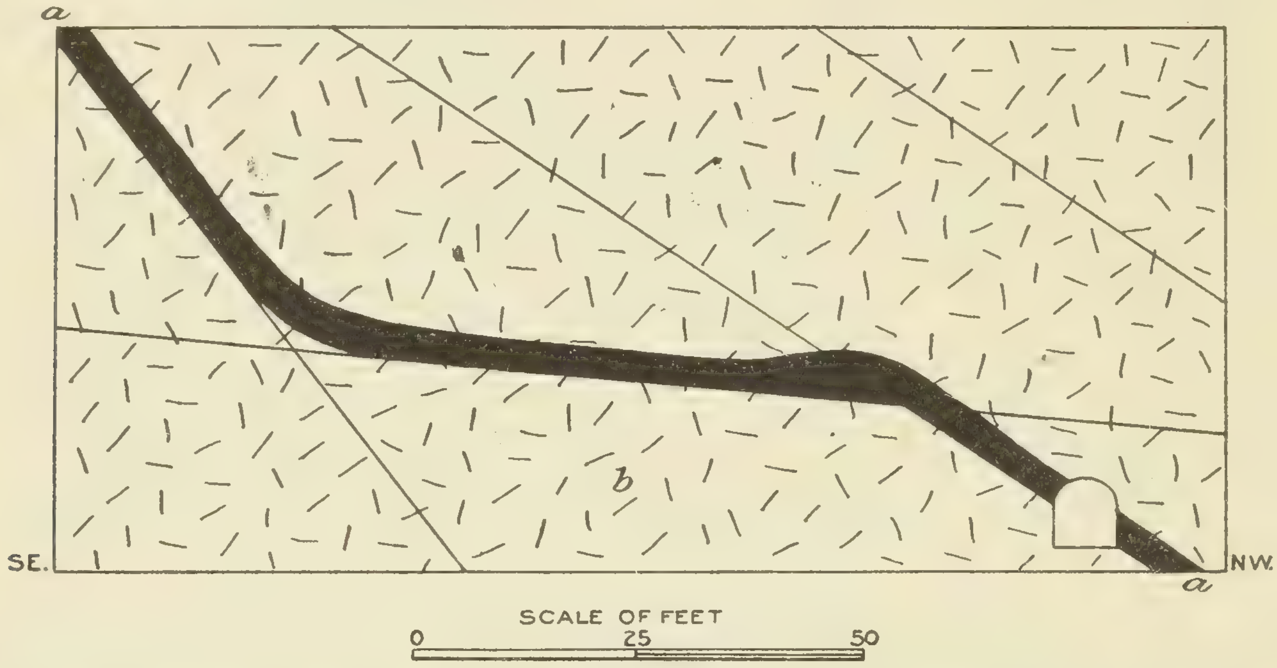


FIG. 116.—Rough vertical sketch section in old surface workings of Pride mine, showing irregular course of vein. *a a*, sulphide ores, rich in galena and blende and carrying relatively large amounts of silver and gold; *b b*, fractured tonalite (country rock).

RELATION OF WALL ROCK TO VEINS ALONG JOINTS.

So far as the writer's somewhat limited observation goes, the chief veins of the Monte Cristo district are confined to the igneous rocks and their vicinity. Among the igneous rocks the tonalite is conspicuous for the number and richness of the veins which occur in it or not far from its boundaries. Next to this the great masses of early andesite show a comparatively large number of veins of varying importance.

Within the tonalite metallic sulphides in large and small segregations are everywhere noticeable. Scarcely a fracture crosses the rock, especially where there is water circulation, but some concentration of sulphides, however slight, may be found along it. Often away from visible fractures there may be found in places bunches of pyrite in the tonalite which have all the appearance of segregations (fig. 117). The fresh rock, as described, has a noticeable abundance of fresh gray metallic minerals, probably chiefly magnetite, which under the action of permeating sulphureted solutions would easily yield these segregated sulphides. From these bunches in the unfractured rock there are all gradations through the slight dissemination of sulphides in the tonalite along minor fractures to the most important joint veins, such as that of the Mystery and Pride mines. The effect of this to the observer traveling over the mountain sides, where the sulphides generally outcrop on the barren rock faces, is strongly to suggest the idea of the derivation of the ores directly by concentration from the tonalite in which they lie.

Within the other igneous rocks, especially, as before stated, the early andesites, there is also a general abundance of pyrites, although not to the same extent as in the tonalite. All the phenomena of mineralization just described, from the segregations to the important veins, may be designated as similar, but throughout less conspicuous and important than in the tonalite.

Between these igneous rocks and the great arkose series, which is the only formation in the district not made up chiefly of directly igneous material, there is a striking difference. As already defined, the arkoses are essentially impure feldspathic sandstones containing comparatively slight portions of the ferromagnesian minerals that were contained in the granitic rock from which they have been chiefly derived. As compared with all the other rocks in the district, this series—best shown on Weeden Creek, where it is nearly free from dike rocks—is remarkable for the absence of impregnations, segregations, and seams of sulphides. At the head of Weeden Creek, where the conglomerate is seamed by perpendicular fractures belonging to the main northeast system, there is no mineralization whatever along the fractures, as was observed both in the field and by study of the rock under the microscope. So far as the writer's experience goes, such areas of entirely unmineralized fractures are rare in the tonalite or the andesite. When, however, the arkose series is traversed by dikes (chiefly of tonalite) the arkose itself is frequently mineralized, although the veins in general do not appear so important as those within the igneous rocks; for example, on the west side of Weeden Creek the Northwest Consolidated mine is located close to the contact of a large dike of tonalite, while elsewhere in the vicinity the arkose is generally without mineralization.

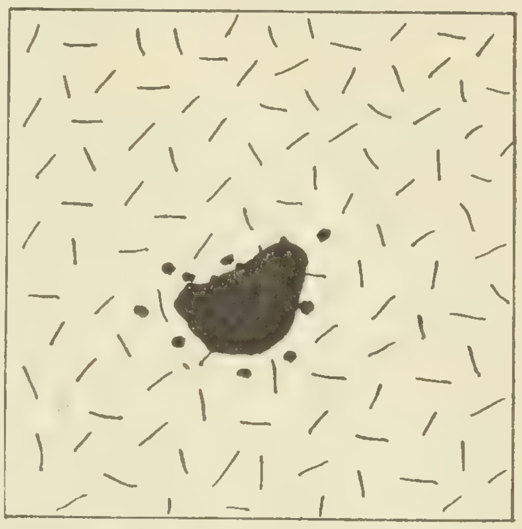


FIG. 117.—Nest of solid pyrite in tonalite without evident jointing outcropping at surface on mountain northeast of Glacier Creek. About one-fifth actual size.

CONCLUSION.

The observations made were not sufficient to warrant any final statement, but a provisional generalization grounded on the facts observed is that the ore in the Monte Cristo district has been chiefly deposited in or near the tonalite, to a less extent in the other igneous rocks, chiefly the earlier andesite, and very little in the sedimentary arkose series. Since the joints along which the ores are formed are found equally well developed in all the rocks, the arkose being as compact as the tonalite, this selective distribution of the ores, if substantiated, must be referred to the influence of the different rocks themselves.

MINERALIZATION ALONG BEDDING PLANES.

The relative importance of veins formed along bedding planes is exceedingly slight. Only one important case was noted, that of the Northwest Consolidated mine, on the northwestern side of Weeden Creek. Even here the bedding planes would perhaps not have been selected as the sites of ore deposition had it not been that slipping has taken place along them, making them more open to circulating solutions. The faulted arkoses here dip very steeply, approaching the vertical.

MINERALIZATION ALONG CONTACTS.

Tonalite contact.—The mineralization along the tonalite contact, in so far as it is governed chiefly by this contact and not by traversing joints or fractures, is mainly of scientific and not of commercial interest. Among the metamorphic phenomena of the contact zone of the tonalite dikes pyritization was frequently observed, associated with silicification. The altered rock has generally been part of the early andesite series. It is hardly possible to say whether the pyrite in this metamorphic zone was recruited from the iron in the andesite or was introduced from the tonalite, but at any rate its formation was probably accomplished by means of solutions attending and called into action by the tonalite intrusion. This contact mineralization is slight, and so far as is known does not reach such importance as to form ore deposits. At Troublesome Pass a specimen of the slightly altered and pyritized andesite showed a trace of gold and 0.44 ounce of silver to the ton.

Enstatite-peridotite contact.—The mineralization along the contact with this rock is also chiefly of scientific interest, as far as this district is concerned. Only one dike of this rock was observed, that which in the upper part of Silver Creek runs from Molybdenum Gulch northward toward the Louise tunnel. In Molybdenum Gulch a rusted vein carrying considerable quantities of sulphides was observed along the dike contact, which here runs at an angle of about 20° to the main jointing. On Silver Creek the Fortunate and Wild Rose tunnels are also apparently located on the contact of the peridotite with slaty quartzite of the arkose series. According to Mr. Peter Chiodo, president of the Bonanza Mining Company, which controls the last-named vein, the pyrites at the Wild Rose tunnel contain copper, mercury, cobalt, arsenic, iron, nickel, gold, and silver.

Summary.—The ores have been deposited to a slight extent along the contacts of tonalite and peridotite, possibly along the contact of other intrusives; to a slight extent along bedding planes, especially where these have been rendered more open by slipping, but at least 99 per cent of the mineralization has been along joints which traverse all of the rocks of the region. These joints are chiefly mineralized in the eruptive rocks, as contrasted with the arkose series, and preeminently in or near the tonalite. The principal mineralization is in a broad belt of especially intense fracturing which runs parallel with the main fractures from Goat Lake through Monte Cristo and down Silver Creek. Within this chief mineralized belt minor zones of maximum fracturing, generally only a few feet across, have afforded a location for the chief veins. Along these veins the ore is not always evenly distributed, there being certain barren although decomposed portions which form the leads connecting the ore bodies. These ore bodies form largely in flattened lenses within the chief vein, generally overlapping one another, and to a less extent at the intersection of transverse joints with the main fracture zone.

HOW THE ORES WERE DEPOSITED.

GENERAL PROCESSES OF ORE DEPOSITION.

REPLACEMENT OF TONALITE, ANDESITE, ETC.

Although the joints or fractures determine the location and direction of the veins, the chief actual mineralization has been by replacement of rocks through which these joints run.

Replacement of tonalite.—Microscopic observation enables us to be reasonably sure that the mineralization of the tonalite is in most cases a process of replacement similar to that process by which sulphides are deposited in limestones, but more complicated on account of the far greater number of chemical changes which the tonalite must undergo by reason of its greater variety of mineralogic constitution. Microscopic examination shows that the tonalite in the vicinity of strong fractures or fracture zones is traversed by many microscopic seams, which are apt to be parallel to one another and to the chief fracture, but which may belong to different intersecting systems. These cracks may traverse all the minerals of the tonalite without crushing or faulting, and it is along them that the earliest and profoundest changes take place, after which the alteration spreads into the less accessible parts of the rock. Decomposition of some of the minerals of the tonalite appears to precede in general any introduction or segregation of metallic minerals. The feldspar is the first to alter, and is transformed into a fine muscovitic aggregate. The pyroxene and biotite also disappear, and are frequently replaced by a fine mat of actinolite. In a more advanced stage quartz grains are found to have grown by secondary enlargement and have often acquired crystal facets, while the original feldspars and ferromagnesian minerals are completely altered to a fine aggregate of calcite and kaolin. Certain areas crystallize as a coarse aggregate of quartz and calcite. Throughout the rock is scattered pyrite in large crystals, which have evidently grown at the expense of the inclosing materials. With a moderate increase of the amount of sulphides this rock becomes an ore, and frequently the sulphides segregate until they make up the entire rock, excluding the other minerals. Generally, however, there is considerable gangue, usually quartz.

Replacement of andesite.—The replacement of the earlier andesite has been especially well observed, and it occurs under the same conditions as does that of tonalite. Like the tonalite, the andesite near the joint zones is apt to be traversed by tiny fractures, perceptible only under the microscope.

In a specimen of the country rock from the Sydney lode, in Seventy-six Gulch, the comparatively fresh andesite showed microscopic veinlets of chlorite and epidote inclosing crystals of chalcopyrite.

A slightly more advanced stage is seen in the wall rock of the O. and B. tunnel. Here the comparatively little altered andesite is traversed by tiny seamlets of crystalline quartz. Quartz may also be found in segregated bunches in the groundmass and in grains down to submicroscopic size, sprinkled thoroughly throughout the rock. Associated with the quartz is some chalcopyrite, which has the same habit.

In a specimen of andesite from Troublesome Pass the feldspar phenocrysts are partly reduced to kaolin and muscovite. The groundmass is partly also muscovitic-kaolinic material, derived from the decomposition of the original feldspathic constituents, but also very largely consists of fine quartz grains which have replaced the other material. Associated with the quartz are scattered crystals and irregular pieces of chalcopyrite. This marks a slightly more advanced stage of silicification and pyritization than the one previously described.

The next stage is seen in a specimen of andesite from the head of Seventy-six Gulch. The feldspar phenocrysts are considerably altered to kaolin, and the groundmass consists of fine microcrystalline allotriomorphic quartz containing large grains of pyrite.

A specimen from a tunnel on the west side of Seventy-six Gulch also illustrates the process of silicification and mineralization. The rock has been reduced to a kaolinic and fine sericitic mass which is throughout penetrated by quartz in isolated grains, clusters, chains, tiny seamlets, etc., so that half the rock is quartz. This is associated with calcite in small veinlets and nests, and chalcopyrite in small isolated crystals.

From the same tunnel as above was obtained a specimen showing a further stage of alteration and replacement, so that it becomes ore. In this rock the areas of fine muscovitic material which formed the residual half of the previously described rock are reduced to a small bulk. The silicification has proceeded until most of the rock is made up of quartz, which varies from coarsely to very finely crystalline, with allotriomorphic granular or retiform structure. The sulphides in the rock are in crystals or irregular grains, either isolated or bunched. They are chiefly blende, but there is abundant kaolin, pyrite, and chalcopyrite.

A still more profound alteration is seen in the ore from the Sydney tunnel, which consists entirely of coarse allotriomorphic granular quartz containing large, irregular grains of pyrite and some chalcopyrite. Of similar character is the ore from the Threadwell and the O. and B. in places. The O. and B. ore is made up of vein quartz varying from coarse allotriomorphic to microcrystalline, also in part retiform, and this quartz is intergrown with allotriomorphic chalcopyrite, arsenopyrite, and pyrite.

Thus we have complete and gradual transition from andesite to a sulphide ore with quartz gangue, by the progressive replacement of the original materials by silica and metallic sulphides. Some calcite is frequently present in the final product as well as in the earlier stages. This process of change is then a true replacement, there being at no time any open space, but the dissolved mineral being placed molecule by molecule with the newly deposited material. The process is essentially the same as in the case of the formation of ores by the replacement of limestone, and is different from the process which is properly called impregnation. The term "impregnation" is properly applied to that process by which minerals are deposited in the tiny, frequently microscopic openings in porous rocks, such as sandstone, etc., and is therefore a distinct process from that of replacement.

DEPOSITION OF MINERALS IN OPEN SPACES.

Deposition in cracks or in breccias (*spaces of discission*).—In the deeper parts of the veins which have been explored there has been a very slight amount of metallic minerals deposited directly along open cracks. There are no true fissure veins in the district, and the spaces between the joints are remarkably small; nevertheless, a slight amount of vein filling, economically insignificant, has taken place.

Near the surface, as has already been explained, the joints are relatively more open than in depth, and along these joints metallic sulphides have been somewhat freely deposited, so that in the surface zone minerals deposited in this way become of some importance in making ore. These sulphides are frequently deposited as crusts, with sometimes a vacant space in the middle. The metallic minerals deposited in this fashion are chiefly chalcopyrite, realgar, and blende.

Both in depth and near the surface there are occasionally places where there has been slight brecciation, so that there are open spaces between the fragments in the breccia. These open spaces have been filled chiefly with quartz and calcite, frequently associated with metallic minerals, and in some cases this mineralization has been enough to form an ore.

Deposition in geodes or irregular cavities (*spaces of dissolution*).—The process of replacement shows the ability of the mineralizing solutions to dissolve the rock mineralized at the same rate as it supplies it with new minerals. If the new minerals supplied to the rock are always equal in amount to those abstracted the process is one of replacement alone, since there are not at any time any open spaces. But we may assume that the solutions varied in quality and sometimes did not bring much metallic mineral into the growing vein. This may be inferred from the frequent layers of pure or nearly pure quartz which are found in the filling of geodes, with sulphides above and below. Owing to some such variation of the nature of solutions it may often happen that the dissolution exceeds the precipitation, in which case the rock acted upon, even though it is continually being mineralized, will become porous, drusy, and honeycombed with many irregular cavities. When, with a renewal of the supply of materials to be deposited, such as gangue and metallic minerals, the ability to deposit again equals the power of solution, or even exceeds it, the metallic minerals and gangue will be deposited in the rock in a manner different from that in which they would have been deposited had not the balance of solution and deposition been temporarily interrupted, for the deposition will now take place in the open pores of the rock and on the wall of the cavities. Thus will originate what Posepny called a "crustified deposit," with layers of different materials, often distinct, building out from the walls toward the center, which is free until the cavity is completely filled.

In the Monte Cristo district there are many ores which correspond to this theoretical conclusion. Many are now solid, the small spaces of dissolution having been entirely filled up, but the difference in character of the filling from that of the rest of the rock betrays the origin. Again, there are numerous cases where the cavities have not been entirely filled and there still remains in the center an air space, into which protrude the perfect crystals of the last precipitation. These empty spaces, it may be remarked, are not found in the barren rock, but only along the veins, which is evidence of their origin by means of the same agencies as those that produced the ore deposition in general. Such mineralization in spaces of dissolution is found in most mining districts, but in Monte Cristo it has relatively very slight importance. They are, however, valuable from a theoretic standpoint, because the crustified minerals which they contain enable us to study the sequence of deposition of the different minerals, which it is very difficult to do where the minerals are deposited by replacement.

GENERAL AGENCY OF ORE DEPOSITION.

The ores in their present position are not original in the rock. They are found only along joints and joint zones, and are evidently dependent upon these fractures, which are later than the inclosing rock. Along these fractures they have formed chiefly by replacement of the country rock, to a much less extent by slow deposition in open spaces. They have, therefore, been formed by some agency which circulated along the relatively open channels afforded by the joints and by the seamed country rock near by. Such agencies, so far as we know, can only be liquid or gaseous. The details connected with the ore deposition, especially the association of minerals, are entirely opposed to the assumption of the agency of gases; therefore the ores must have been deposited by liquid solutions—i. e., by circulating underground water—to which conclusion, moreover, every indication points.

RELATIVE AGE OF MINERALS.

As before stated, the ores of the Monte Cristo district, where they have originated by replacement, do not generally show any definite succession of minerals. However, in the case of portions of the vein where small fissures or dissolution cavities have been filled, there is generally a definite order of deposition observable. In such specimens a given mineral may make up a definite layer with layers of other minerals above and below, and it may often occur in two generations—i. e., in two distinct layers separated by a different mineral.

Some of the best specimens for observing the order of deposition of minerals were selected and studied. The facts afforded by this study have been tabulated as follows:

Table of observed succession of minerals in ore specimens from the Monte Cristo district.

[The column numbers 1 to 5 indicate succession of minerals from oldest to youngest.]

Locality.	1.	2.	3.	4.	5.
Last Hope tunnel	Pyrite, arsenopyrite, pyrrhotite, blende.	Calcite and quartz.			
Mystery mine	Sulphides and quartz.	do	Arsenopyrite		
Prospect tunnel, Poodle Dog trail.	Pyrite	Quartz	Pyrite		
Mystery mine	Chalcopyrite	do	Calcite		
Do	Quartz and sulphides.	do	Realgar		
Do	do	Calcite			
Do	Blue amphibole	Quartz	Stibnite	Calcite	
Mountain northwest of Mystery mine.	Chalcopyrite, arsenopyrite, and quartz.	do	Blende		
Tunnel south side of Silver Lake.	Blende	Calcite	Chalcopyrite		
Do	do	Chalcopyrite	Galena	Calcite	

Table of observed succession of minerals in ore specimens, etc.—Continued.

Locality.	1.	2.	3.	4.	5.
Threadwell tunnel	Blende	Chalcopyrite	Quartz and calcite.		
Do	Quartz	do			
Last Hope tunnel	Arsenopyrite	Quartz	Chalcoyprite and pyrrhotite.		
Do	Arsenopyrite and quartz.	Chalcopyrite and pyrrhotite.	Calcite		
Red Gulch	Quartz	Chalcopyrite	Molybdenite		
Seattle tunnel	Quartz and pyrite.	Hematite	Chalcopyrite		
Do	Quartz	Chalcopyrite	Melaconite		
Louise tunnel	Arsenopyrite	do	Calcite		
Do	Quartz	do			
Northwest Consolidated tunnel.	Blende	do	Pyrrhotite and galena.	Quartz	
Tunnel in Pearsall Gulch.	Epidote	Quartz	Chalcopyrite	Calcite	
Northwest Consolidated tunnel.	Galena and blende.	Chalcopyrite	Calcite		
Tunnel west side Seventy-six Gulch.	Quartz	Blende and galena.			
Do	Arsenopyrite, chalcopyrite, and quartz.	do	Chalcopyrite		
Do	Arsenopyrite	Chalcopyrite	Blende and galena.	Quartz	Calcite.
Foggy tunnel, Goat Lake.	Blende and galena.	Chalcopyrite and realgar.			
Do	Arsenopyrite, pyrite, and quartz.	Chalcopyrite	Quartz	Stibnite and realgar.	
Do	Arsenopyrite, and quartz.	do	Blende	Quartz	Realgar, blende, and chalcopyrite in druse.
Do	Blende	do	Stibnite	Realgar	
Do				do	Chalcopyrite.
Do	Arsenopyrite			Quartz, realgar, and blende.	Stibnite.

The writer has classified the above facts in a number of different ways, so as to find out their general bearing. Without wearying the reader with these intermediate steps, however, the following results will be given:

Arsenopyrite.—In nearly every case arsenopyrite is among the oldest of minerals, generally occurring in such a way as to show it to be of greater age than chalcopyrite, pyrrhotite, galena, blende, stibnite, realgar, or calcite. It is found intergrown with and therefore contemporaneous with pyrite and quartz, more rarely with pyrrhotite and chalcopyrite. Yet in a small way arsenopyrite occurs among the latest of minerals, always, so far as observed, in a second generation of insignificant importance as compared with the first. In specimens from the Mystery mine arsenopyrite has been found intergrown with and resting upon calcite. This calcite, which is often intergrown with quartz, is a cavity filling resting upon the earlier-formed massive ore, consisting largely of arsenopyrite and quartz.

Realgar.—Realgar is properly contrasted here with arsenopyrite, since its occurrence shows that it is certainly in every case the result of alteration of the former mineral at a certain distance from the surface of the ground. The realgar is found along cracks in the arsenopyrite ores, which cracks in every case extend toward the surface, and it is also found forming part of the incrusted minerals in druses. In the hand specimens studied, incrusted realgar has been found to be younger than arsenopyrite, pyrite, chalcopyrite, galena, blende, and stibnite. It is found intergrown and contemporaneous with copper pyrite, stibnite, blende, and quartz. As younger-formed minerals only chalcopyrite and stibnite have been observed. Realgar forms only one generation, so far as studied, and it has evidently been derived from the arsenopyrite by the dissolution of this mineral and the subsequent precipitation of a pure arsenic sulphide, the iron being carried away.

Stibnite.—Stibnite is found closely associated and intergrown with realgar, and generally occurs as minute free crystals crusting the walls of little druses which have been dissolved out of the older ores. Only calcite and realgar have been found later than this mineral. On the other hand, in different specimens it has been found to be distinctly later than arsenopyrite, chalcopyrite, blende, realgar, and quartz.

The occurrence of stibnite in druses, as above mentioned, and its intimate relation to realgar make it plain that, like realgar, it is a secondary mineral derived from the older sulphides by a process of purification consisting in dissolving the original sulphides and precipitating some of the metals in scattered form as pure sulphides while the other metals are removed in solution.

Calcite.—Calcite is closely associated with realgar and stibnite. In nearly every specimen examined calcite has been the last mineral to crystallize, or among the last. Only scattered crystals of arsenopyrite in one case and chalcopyrite in another, both belonging to a late generation distinct from the main period of precipitation of the sulphides, have been found younger and resting on the calcite. In every other case calcite has been found younger than all other minerals, such as arsenopyrite, pyrite, chalcopyrite, pyrrhotite, galena, blende, and stibnite. It is not infrequently found intergrown with quartz.

Calcite occurs in only a single generation. This period of deposition in reference to the other minerals is, therefore, recent, being about the same as that of realgar and stibnite.

Galena.—Galena also occurs, so far as observed, only in one generation. It occurs in different specimens, both older and younger than chalcopyrite and quartz. It frequently occurs older than calcite, and once was found older than realgar, although galena and realgar are generally not associated. It was noticed in one case intergrown with pyrrhotite, but its most intimate associate is blende, with which in the majority of cases it is crystallized simultaneously.

Therefore, the position of galena in relation to the already-described minerals may be said to be younger than arsenopyrite and older than calcite and realgar. This also accords with certain field observations to be discussed in another part of this report.

Blende.—On account of the close association of blende with galena this mineral will now be considered. Like most of the other sulphides, blende occurs freely intergrown with quartz in many specimens; in others it is older than the quartz, and in still others younger. It is almost always older than calcite, and was twice observed older than stibnite. It is generally younger than arsenopyrite, but is sometimes intergrown with it. It occurs not infrequently intergrown with realgar, but more often is older than this mineral. It also occurs intergrown with pyrrhotite and pyrite. Its relations to copper pyrite are interesting, having been in nine cases observed to be older, once intergrown, and twice younger. It is closely associated with galena, with which it is intergrown.

Although the facts of the association of blende indicate a rather extended period of precipitation, in general its maximum precipitation was subsequent to that of arsenopyrite and before that of calcite and stibnite.

Chalcopyrite.—Chalcopyrite will be next taken up on account of its relation to blende, as above noted. This mineral occurs in a great variety of positions with reference to others. It occurs frequently younger than arsenopyrite, but occasionally intergrown with it. On the other hand, it is almost always older than calcite. So far as observed it is older than stibnite. While it has not been definitely noted as intergrown with galena, the fact that it is in three cases older than this mineral and in two cases younger shows that they were partly contemporaneous. The same is true of the relation of chalcopyrite with blende, with which mineral, moreover, it has been observed to be intergrown. It has also been observed intergrown with pyrrhotite. In the two specimens where pyrite and chalcopyrite were noted in distinct relation the chalcopyrite was the younger. Moreover, in a thin section of ore from the Sydney lode the pyrite appears to have altered to chalcopyrite along cracks and along the margins of crystals. In one remarkable case a crust of chalcopyrite was observed overlying a crust of hematite, both being parts of the filling of a tiny crack formed by contraction of the rock near the surface. The hematite in this case was plainly derived from the oxidation of pyrite, which with quartz had formed in the rock previous to the formation of these cracks.

In general, chalcopyrite appears to be relatively younger than arsenopyrite, although the two have sometimes been precipitated simultaneously. It is generally older than calcite, but not always. It is not very closely associated with any other mineral, but has most frequently been precipitated simultaneously with pyrite and blende. While its association with arsenopyrite shows its precipitation early in the succession of minerals, its intergrowth with realgar shows that its precipitation lasted very late. This is emphasized by its occurrence as scattered crystals resting on calcite, which is among the latest of minerals. Finally, the occurrence of chalcopyrite resting upon hematite derived from the oxidation of pyrite induces the conclusion that chalcopyrite has been the most persistent of sulphides and the very last to form, it having been precipitated in the last-mentioned case within the borders of the zone of oxidation. Chalcopyrite has been observed in two generations in a single specimen.

Pyrrhotite.—Pyrrhotite is most closely associated with chalcopyrite, being frequently found intergrown with it. It has also been observed intergrown with blende, galena, and pyrite. It is generally younger than arsenopyrite, but is sometimes intergrown, and is generally older than calcite.

Pyrite.—Like pyrrhotite, not many observations have been made upon the relative age of this mineral. Among the sulphides its most intimate associate is arsenopyrite. It has been found intergrown with pyrrhotite and blende, and has been observed older than calcite, chalcopyrite, stibnite, and realgar. In some specimens it occurs in two generations, with generally a layer of quartz between.

Quartz.—Quartz is the most widespread of all the minerals in the ores. It has been deposited in large quantities contemporaneously with the earliest and latest of minerals; for example, it is almost always intergrown with arsenopyrite, and frequently with calcite. It is fully contemporaneous with blende, chalcopyrite, and galena. As might be expected from this persistence, quartz occurs in many generations, several of which may frequently be observed in a single crustified specimen.

Molybdenite.—This was observed only once, overlying quartz and chalcopyrite which had formed along cracks. In this case it had a very young appearance, and is probably to be classed with stibnite as among the latest of secondary products.

Epidote and blue amphibole.—These are found largely developed in the rocks forming the walls of the ores and in some of the ores. Epidote is characteristic of the altered andesites; blue amphibole is frequently found in the altered tonalites. Their relation to the sulphides and ordinary gangue minerals, such as quartz and calcite, have not been exhaustively studied, but so far as observed they belong to the oldest minerals in the series.

Melaconite (?)—This has been observed as the alteration product of chalcopyrite.

MAIN FEATURES OF RELATIVE SUCCESSION OF MINERALS.

The study of specimens, the results of which have been brought out in the preceding paragraphs, shows that there is a definite though rude order of succession of the different minerals in general, which order is complicated by the occasional deposition of minerals after their real maximum periods of formation. Quartz is the only mineral which has been continuously and regularly precipitated through the whole period of mineralization. The other gangue, calcite, has been precipitated only at the extreme latter end of the process. Epidote and blue amphibole probably were formed during the earliest steps. Among the sulphides arsenopyrite and pyrite are the oldest; then come chalcopyrite, pyrrhotite, blende, and galena. Of these, which are in a large way contemporaneous, chalcopyrite has been the most persistent.

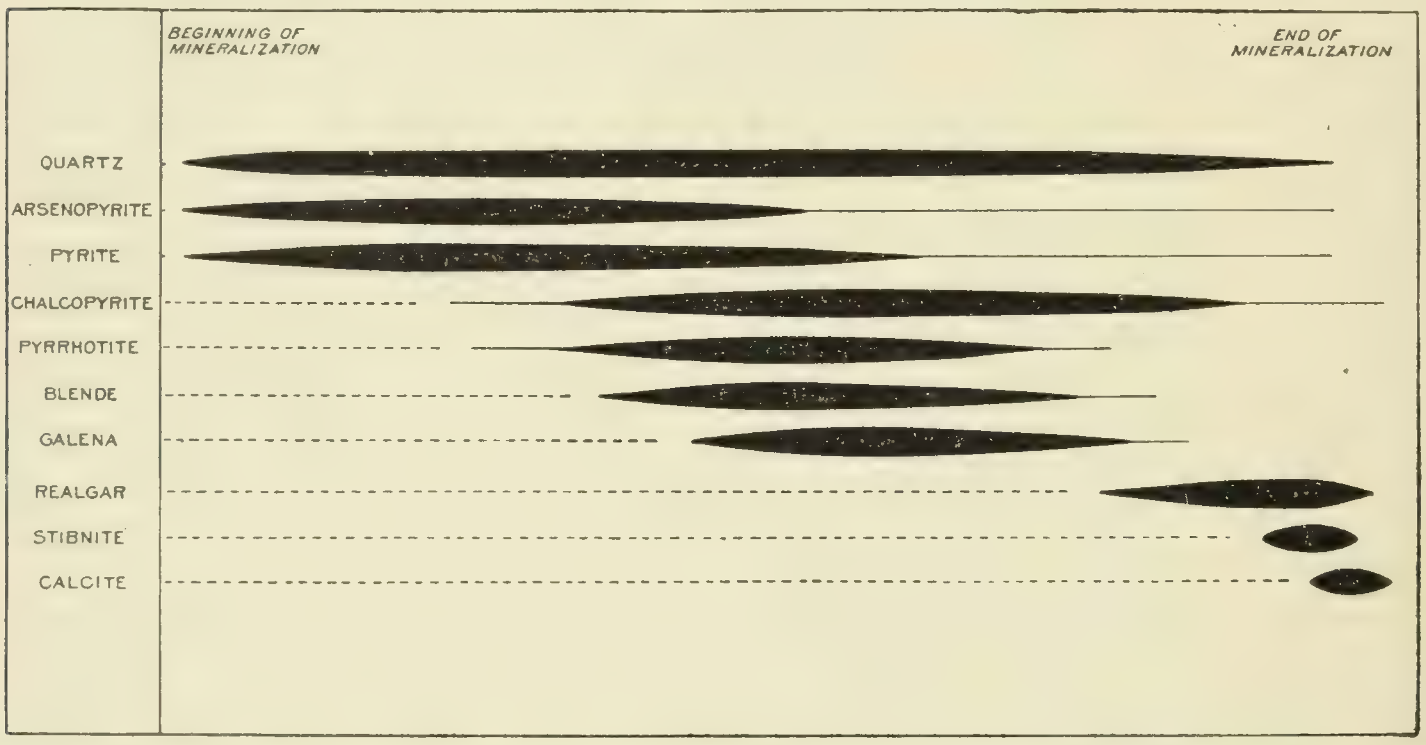


FIG. 118.—Ideal diagram showing relative succession of minerals in any one locality. (Deduced entirely from study of specimens showing crustified minerals.)

Finally came the period of precipitation of realgar, stibnite, molybdenite, etc., all undoubtedly the results of secondary concentration of already-formed minerals. The calcite was roughly contemporaneous with this third period, and some of the earlier minerals, notably chalcopyrite, were still sparsely formed.

We may, therefore, define three chief periods of sulphide formation.

1. Arsenopyrite and pyrite (gangue, quartz).
2. Chalcopyrite, pyrrhotite, blende, and galena (gangue, quartz).
3. Realgar, stibnite (molybdenite) (chalcopyrite) (gangue, quartz and calcite).

(See Pl. LXXXII, *B*.)

The relation of the different minerals as regards their periods of precipitation, as worked out above, is graphically represented in the diagram forming fig. 118. This represents the changes which have been noted in the ores available for study, and shows the relative age of different minerals where these occur in association. The succession, therefore, is one which can be applied only to a single locality. If we suppose two distinct localities, especially where one is more deep seated than the other, then we can readily believe that in these two localities the deposition of minerals belonging to different portions of the succession, as above worked out, may go on simultaneously.

RELATIVE POSITION OF MINERALS.

Although nearly all the minerals above enumerated occur associated together in various picked specimens, yet on a large scale many of them have definite positions separated from the positions of others.

Position of galena.—Of all the minerals galena has the most definite position. In the Mystery and Pride mines no galena whatever has been found below a certain zone which extends from the surface to a depth of 50 to 250 feet, averaging perhaps 100 or 150 feet (fig. 119). Below the limit at which recognizable galena is found, the other sulphides, notably arsenopyrite, pyrite, and chalcopyrite, show on analysis some lead, according to Mr. Sutton, the mine superintendent, but this lead is found only to a depth of about 300 feet below the surface, thus extending a comparatively slight distance below the galena zone. Farther down, in the deeper

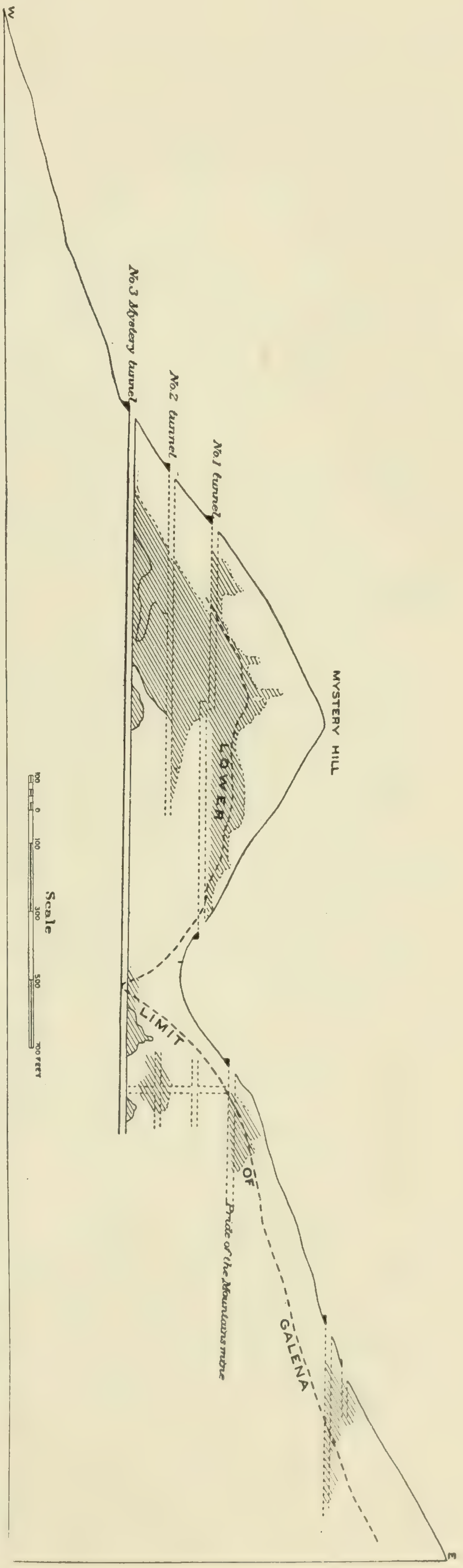


Fig. 119.—Vertical longitudinal section on Mystery-Pride vein, showing lower limit of galena zone. Ore extends nearly all along the vein. Shaded portions are developed bodies of pay ore.

workings, the arsenopyrite, pyrite, and pyrrhotite, which form the bulk of the ores, are almost always free from lead. The accompanying cross section shows the position of the galena zone in these mines.

The same general condition is found in the other mines of the district, but generally not so well displayed, on account of the slight amount of exploration. In the Foggy tunnel at Goat Lake the exploration has, indeed, been carried to a considerable depth, but here the zones with reference to the surface are not so regular, on account of the occurrence of strong intersecting water courses along which the minerals have formed. Along these courses the minerals of a certain zone penetrate far more deeply than in the rest of the rock, producing great irregularity. For this same reason, also, the ore has formed chiefly as heavy shoots at the intersection of the water courses, while the rest of the courses are barren, instead of having formed as a regular vein, as is the case in the Mystery and Pride. Galena is not abundant in the Foggy tunnel. It occurs in the Main tunnel at about 400 feet from the surface, and in the Discovery tunnel about 200 feet from the surface, showing that it penetrates more deeply than in the Mystery and Pride.

Position of blende.—Blende is closely associated with galena, but penetrates downward below the lower limit of this mineral. The relation of blende to the surface is recognized by the most observant mining men of the Monte Cristo district. According to Mr. Sutton, manager of the Monte Cristo mines, the blende penetrates deeper than the galena, but less deep than chalcopyrite. Below the limit of blende determinable quantities of zinc are nearly always found in the chalcopyrite.

The veins cut in the Louise tunnel carry blende at the surface, which in depth gives place along the same vein to arsenopyrite. This fact was recognized by Mr. Peter Chiodo, president and manager of the mine.

The mines mentioned are the only deep workings in the Monte Cristo district. The Foggy mine at Goat Lake, as before stated, shows no great development of galena and blende, but certain other mines near Goat Lake show surface ores exactly like those of the Monte Cristo district, consisting chiefly of galena, blende, and chalcopyrite, with quartz gangue.

Many smaller mine workings in the Monte Cristo district illustrate the same principle. Near the outcrop abundant blende and galena is generally found, which disappears almost entirely a few hundred feet from the surface. This may be observed in several tunnels on Seventysix Gulch.

Position of chalcopyrite.—Chalcopyrite in the Monte Cristo district is everywhere associated with blende and galena in the surface zone. It penetrates, however, deeper than either of these minerals, but in the lower workings of the Monte Cristo mine, according to Mr. Sutton, the arsenopyrite, pyrite, and pyrrhotite, which make up the ores, generally are without any important admixture of chalcopyrite.

Position of realgar.—In the Mystery and Pride mines realgar is not known in association with galena, but occupies a lower zone. Nevertheless it has a close dependence upon the surface, and is characteristic of a zone below the galena zone and above the unaltered pyrite and arsenopyrite zone. It occurs along cracks in the arsenopyrite ore and as crystals coating the walls of geodes, always in such a way as to prove its secondary and comparatively recent formation. Mr. Sutton, in a letter to the writer, states that realgar in these mines always occurs in a streak which extends in an almost straight line from the surface.

In the Foggy mine, as might be expected from the heavy fracture zones which have already been mentioned, realgar is found deeper than in the Monte Cristo mines. It is found coating joints throughout the Foggy workings to a point at least 1,000 feet from the surface. In one case realgar had apparently formed on the fresh wall of a drift subsequent to its opening.

Position of arsenopyrite.—Arsenopyrite is found throughout all the ores, both near the surface and distant from it. At the surface, however, it is associated with and sometimes entirely replaced by blende, galena, and chalcopyrite. Farther down these minerals decrease, until below a certain point, which in the Mystery and Pride mines may be stated as approximately not more than 500 feet below the surface, arsenopyrite forms the principal mineral, being associated chiefly with pyrite and pyrrhotite.

Position of pyrite and pyrrhotite.—The position of pyrite is practically that of arsenopyrite. Pyrrhotite is also closely connected, but is found more often than the others closely associated with chalcopyrite.

Position of gold and silver.—The gold and silver in the ores are chiefly contained in the sulphides, arsenopyrite, pyrite, pyrrhotite, galena, chalcopyrite, and blende. According to Mr. Sutton the arsenopyrite carries the most gold, pyrite and galena the most silver. Pyrrhotite, however, is supposed to be comparatively barren in these values as compared with the others, and realgar is supposed to contain neither gold nor silver.

The surface ores are nearly always the richest in gold and silver. In the Mystery and Pride, according to Mr. Sutton, the average content of the surface ores has been 0.95 ounce of gold, 12 ounces of silver, 4 per cent of copper, and 5 per cent of lead. The average of the deeper-seated ores, including probably the transition zone between the surface ores and the unaltered arsenopyrite ores, has been, according to the same gentleman, 0.6 ounce of gold, 7 ounces of silver, 1 per cent of copper, and 2½ per cent of lead.

It follows naturally from this distribution of the values that the richest ores have been generally high in galena and blende.

Résumé.—In the Monte Cristo district in general the surface ores are marked by galena, blende, and chalcopyrite, with pyrite and arsenopyrite. They are also the richest ores in precious metals, the values having decreased with depth in every well-observed case. In depth the leaner ores consist chiefly of arsenopyrite and pyrite, with pyrrhotite, and with the partial or complete exclusion of galena, blende, and chalcopyrite. In the Goat Lake district the conditions are the same as at Monte Cristo. The Foggy mine, however, which is the most important working mine, differs in detail. In this mine galena, blende, chalcopyrite, and calcite are rare, the purely arsenopyrite ores approaching more nearly to the surface. In this case the surface zone, although present, is not extensively developed, a peculiarity which may be explained away by supposing extra-rapid erosion, so as to prevent the formation of such a zone on so complete a scale as at Monte Cristo. On the other hand the Foggy mine differs from the Mystery and Pride mines in having a greater abundance of realgar and stibnite. When it is remembered that realgar and stibnite, which are closely associated, are evidently secondary minerals derived from solution and partial redeposition of the older minerals, it will be seen that this difference must be due to greater access of circulating waters in the case of the Foggy mine. This is actually the case, the water found in the Foggy tunnel being many times more abundant than that in the Mystery and Pride. This, again, depends upon the presence of the powerful intersecting fracture zones of the Foggy mine, which are more important than those found in the Monte Cristo mines.

The sulphides, therefore, separate themselves according to their location into two classes, which are recognized by the miners and called the surface ores and the deeper ores. They may be defined as follows:

(1) Deep-seated zone. Characterized by arsenopyrite, pyrite, and pyrrhotite, with other minerals subordinate. This underlies the surface zone and reaches to a depth not yet determined.

(2) Surface zone. Characterized by an abundance of galena, blende, and chalcopyrite. These are generally associated, yet not always. The galena zone is shallowest and is overlapped by the blende zone, and this by the chalcopyrite zone. Under ordinary conditions, where there are no deeply penetrating and relatively open fracture zones, the galena zone does not extend much more than 300 feet below the surface. The chalcopyrite zone has not been carefully studied, but probably extends in general no more than 300 feet below the limit of galena, while the lower limit of the blende appears to occupy an intermediate position.

Comparing these classes of minerals, divided according to relative position, with the classes already established on the basis of relative age, we find that the two groups No. 1 coincide, the oldest minerals being those of the deep-seated zone, and also that the groups No. 2 coincide, the minerals intermediate in age being those of the surface zone—that is to say, the surface zone, from the evidence of succession of minerals, independently adduced, is younger than the deep-seated zone. This correlation leaves out the group 3 of minerals classified according to relative age, which are the latest formed. These occur in so small a quantity, with other ores always largely predominating, that they are not properly described as forming a separate zone. Nevertheless, they occur in a definite position. They may be said to be characteristic of the transition zone between the surface belt and the deep-seated region. Of the minerals of this newest-formed class, realgar is the most reliable guide to their general position, on account of its being relatively abundant and always conspicuous. This mineral forms along cracks and in geodes under the galena zone, but these cracks connect with the surface and extend only a certain distance downward.

Therefore the three chief groups of sulphides according to relative age occupy definite, though rude, zones, the oldest group being below, the intermediate above, and the youngest occurring in the transition zone between the other two.

OXIDIZED ORES.

To the sulphides may be added as a fourth class of ores those that are oxidized, these naturally having the uppermost position. Therefore we have already four zones, each characterized by its especial association of minerals: (1) Oxidized zone, (2) upper sulphide zone, (3) intermediate sulphide zone, (4) lower sulphide zone.

CHARACTERISTICS OF ORE ZONES.

OXIDIZED ZONE.

The relative importance of the oxidized zone in the Monte Cristo district is slight. The sulphides generally outcrop at the surface, although the oxidation extends below the surface along the more open cracks for a short distance. The zone of complete oxidation was not observed as extending more than 10 feet below the surface at any place, and is generally entirely lacking. Oxidation along streaks was noted as extending as much as 150 feet below the surface in the O. and B. mine, although at the same mine most of the vein outcrops as sulphides.

Among the results of oxidation limonite and malachite were noted, both of which are found in process of actual precipitation in prospect tunnels by percolating waters. Rarely the pyrites at the outcrop of a vein are leached out from the inclosing quartz for a few inches or feet, forming the familiar honeycombed quartz.

UPPER SULPHIDE ZONE.

The upper sulphide is commercially the most important of all zones. As before noted, it carries the greatest values of gold and silver. It is well developed throughout the Monte Cristo district and in the neighboring country.

RELATIVE AGE.

Evidence from relation to lower sulphide zone.—It has already been determined, by comparison of different minerals occurring together in many selected specimens, that the minerals characteristic of the upper sulphide zone are in general later than those characterizing the lower sulphide zone, and therefore it follows that the upper zone itself is the younger.

Evidence from conformity of lower limit of upper sulphide zone to the surface.—The relation of the upper sulphide zone to the surface is everywhere evident. In almost every case the surface itself constitutes the upper limit of this zone, for here ores rich in the sulphides, galena, blende, and chalcopyrite, everywhere outcrop. It is plain also that at a certain distance below the surface this zone disappears. Since this condition is almost universal, so far as known, a general parallelism of the upper sulphide zone to the surface may be deduced. This relation is seen in actual, careful observations made in the Mystery and Pride mines, and is shown in the accompanying cross section. The lower limit of galena, which is the most characteristic mineral of the upper sulphide zone, as shown, follows closely the present topography, which is highly accentuated as the result of rapid Pleistocene stream erosion. Below this limit no galena has been found in the ores. Of the truth of this statement the writer has been assured by Mr. Sutton, the superintendent of the mines, who also kindly sketched the line indicating the lower limit of the galena zone.

From these observations it appears that the upper sulphide zone is constantly associated with the surface, however irregular this may be, is dependent upon it, and is a function of it. This being the case, the upper sulphide zone, as it at present is, can be no older than the present topography. Now this topography, as has already been stated, is almost entirely Pleistocene, the magnificent deep valleys having been eroded out of a nearly level plateau uplifted in late Pliocene or early Pleistocene time. Where the deep cutting of these valleys has taken place portions of the plateau between them have been differentiated into lofty and rugged mountains. The present topography evidently represents the most recent stage of this erosion, and its period of formation extends from a short distance back in the Pleistocene down to the present day.

Evidence from irregularity of veins in upper sulphide zones.—Near the surface, as already described, the ore deposits often become irregular in location, in strike, and in dip. They are often branching and often abruptly cut off. In this they differ markedly from the ore deposits in the same veins at a greater depth, where they are confined almost entirely to well-defined and steeply dipping zones having a regular and straight strike. The irregularity of the veins near the surface has been shown to be dependent upon the greater openness of the joints as the surface is approached, as compared with the condition in depth. In depth the joints are mostly tight, only the zones of maximum fracturing (which belong chiefly to the predominant east-northeast striking and steeply northwest dipping set) being sufficient to allow much water circulation. For this reason these zones of maximum fracturing have obtained a practical monopoly of circulation, and hence of ore deposition. Near the surface, however, the whole rock becomes looser, all the minor joints open, and circulation is much freer and follows more irregular channels. In proportion as this becomes the case the ores also become irregular, having been deposited along these somewhat tortuous water courses. This relatively greater abundance of joints has been shown to be a function of the surface and to be caused partly by movement in the surface rocks consequent upon the action of gravity, and partly, probably, by a certain degree of solution by circulating waters within the surface zone, by which process the surface rock shrinks and the traversing joints enlarge. Since ores of the upper sulphide zone have been deposited in joints which have been opened and enlarged by the rock which they traverse coming close to the surface, these ores must have been deposited since the formation of approximately the present surface.

Conclusion.—The conclusion from these different lines of reasoning is harmonious—that the upper sulphide zone has originated since the formation of approximately the present topography, of which it is a function.

DIRECTION OF MINERALIZING SOLUTIONS.

It has already been concluded that the ores in general were deposited from solutions in circulating waters. As to the general direction of the solutions in the upper sulphide zone we have fairly convincing testimony.

Evidence from occurrence and shape of ore pockets.—Cases are numerous in the Monte Cristo district where the occurrence and shape of ore pockets point to deposition from downward-moving waters. As already described, a favorite place for the deposition of sulphides has been at the intersection of two joints, generally a steeply dipping and a more flatly dipping one. In many cases the ore has been deposited entirely in the bottom of the trough formed by such intersection, without any considerable amount being deposited beneath, in the roof which the intersecting joints have formed, entirely similar to the trough above, although reversed in position. If the waters had been ascending, the solutions would have naturally converged under this roof and would have there been precipitated more easily than in the overlying trough, but this the writer has not observed. The accompanying figures show much more graphically than any descriptions could the usual state of affairs. Of these the most striking is fig. 120, showing ore deposited almost exclusively in troughs formed by intersecting joints, as above described. Another striking example, shown in fig. 121, is 95 feet from the surface, but yet within the upper sulphide zone. Here a slight movement has created a breccia, which by subsequent decomposition has become an almost impermeable layer. Within this breccia, and along the joints immediately above it, sulphides (chiefly blende and pyrite) have been deposited, but along the continuation of the same joints, below the impermeable layer, there has been no mineralization whatever. Fig. 122 is a sketch section of a vein outcrop, showing how the mineralization has taken place by preference in the troughs of intersecting veins. Fig. 123 is another sketch of a vein opening where the mineralization has taken place at the intersection of two important fracture systems. A tunnel has been driven at the actual intersection, where was found the richest ore. A short distance above the intersection, on the main fracture zone, there is no mineralization. Examples like this are to be explained only by the hypothesis that the waters which produce the deposition of the sulphides were distinctly downward moving.

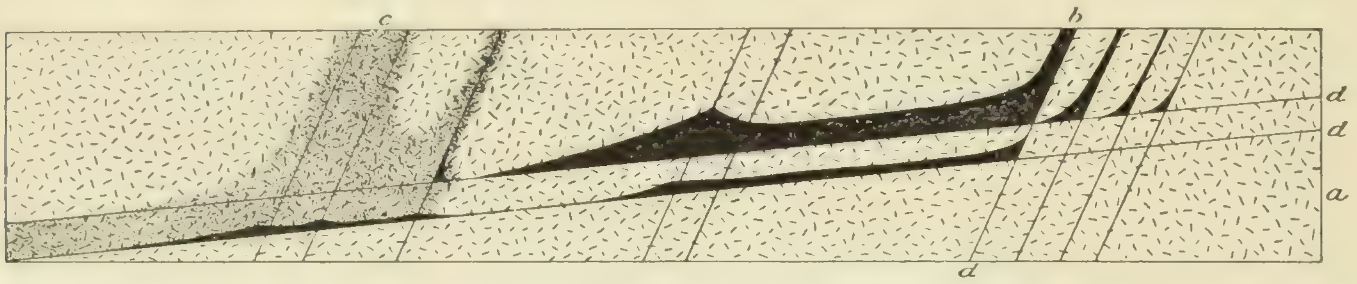


Fig. 120.—Diagrammatic sketch of portion of wall of upper Seventy-six tunnel at mouth, showing deposition by descending waters at intersection of fractures. *a*, andesite; *b* (black portions), solid sulphide ore (arsenopyrite, pyrite, chalcopyrite, blende, gangue, calcite, and quartz); *c*, andesite, iron-stained and strongly impregnated by sulphides; *d d*, etc., barren fractures, generally not even iron-stained. The fractures whose intersection with the tunnel wall is nearly flat have really a steep dip away from the observer; therefore the ore troughs have also a steep pitch in this direction. Scale, 1 inch = 10 feet.

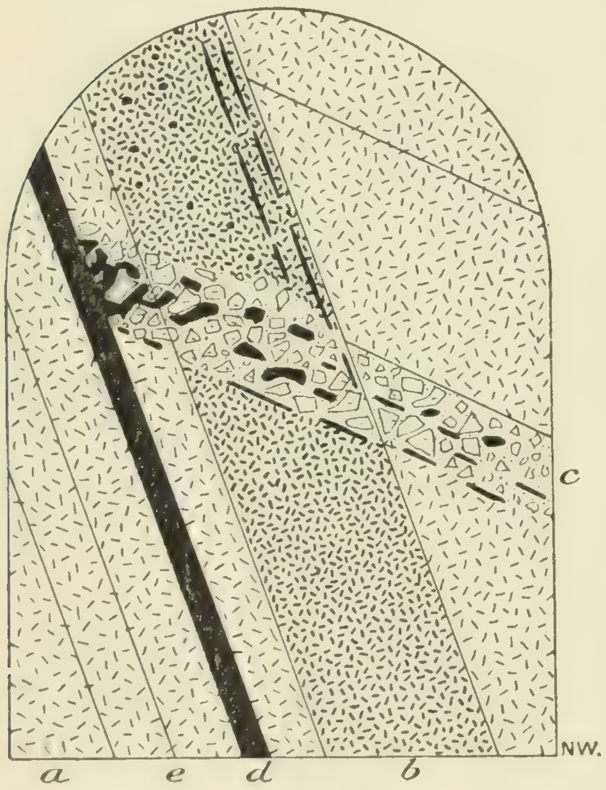


Fig. 121.—Sketch of breast of tunnel on west side of Seventy-six Gulch, 95 feet from the surface. *a*, hard andesite; *b*, soft, decomposed andesite; *c*, breccia (premineral); *d*, sulphides (blende and pyrite); *e*, fractures. Scale, 1 inch = 3 feet.

Another observation which tends toward the same conclusion is that within the veins the foot-wall streak is usually the largest and richest. As already explained, the veins generally consist of a zone of fractures, all equally available for solutions. Where the veins are dipping, however, it is manifest that downward-moving solutions will travel by preference along the foot wall of the vein, in case the solutions are so limited that the whole available space is not filled, and in case the relative openness of the fractures is equal throughout the zone. On the other hand, if the solutions were rising it would be most natural for them to seek out the hanging wall. The generally greater richness of the foot wall streak is shown in fig. 127, which is typical of many occurrences.

Evidence derived from a comparison of the downward succession of minerals with their relative solubility.—The downward succession of minerals within the upper sulphide zone is in general, as already stated, (1) galena, (2) blende, (3) copper pyrite. Below this the lower sulphide zone is characterized chiefly by pyrite and arsenopyrite.

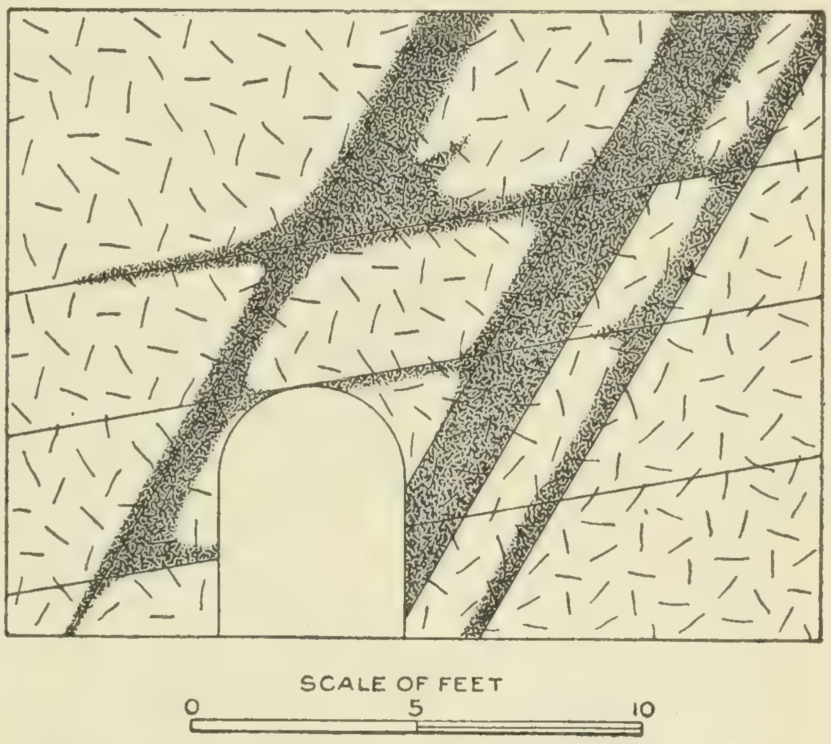


Fig. 122.—Sketch section of tunnel and vein exposure in vertical cliff, Glacier Creek, showing mineralization along joints by probably descending waters. Shaded areas represent impregnation of tonalite with sulphides along joints, sometimes becoming solid ores.

Recently important contributions to the study of ore deposits have been made by Messrs. Van Hise,[1] Weed, and Emmons. These writers have enunciated the principle of solution and reprecipitation of sulphides by descending waters, involving concentration of certain constituents. Messrs. Van Hise and Weed have concluded that the main agency of precipitation of these sulphides was iron pyrite. Mr. Weed gives the chief minerals in the order of their facility of attack by oxidizing waters (which is consequently the inverse order of their facility of precipitation by iron sulphide) as arsenopyrite, pyrite, chalcopyrite, blende, galena, and chalcocite. Leaving out chalcocite, which is rare at Monte Cristo and has not been much studied, this order of relative facility of precipitation corresponds with the order of the minerals as distributed in a broad way from the surface downward. Since the uppermost minerals are those most easy of precipitation, and the downward ones successively more soluble, it is probable that the solutions deposited in this series were downward moving.

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[1] Trans. Am. Inst. Min. Eng., Vol. XXX.

Professor Van Hise[1] and Professor Chamberlin[2] have described the lead and zinc ores of the Upper Mississippi Valley. Both emphasize the fact that the galena is generally found overlying the blende. Professor Van Hise observes in this connection:[3]

> If it be premised that the ascending waters evenly distributed the sulphides, at least so far as the vertical limit is concerned, *it is certain that downward-moving waters, combined with denudation, may concentrate the galena at high levels and the sphalerite at lower levels.*

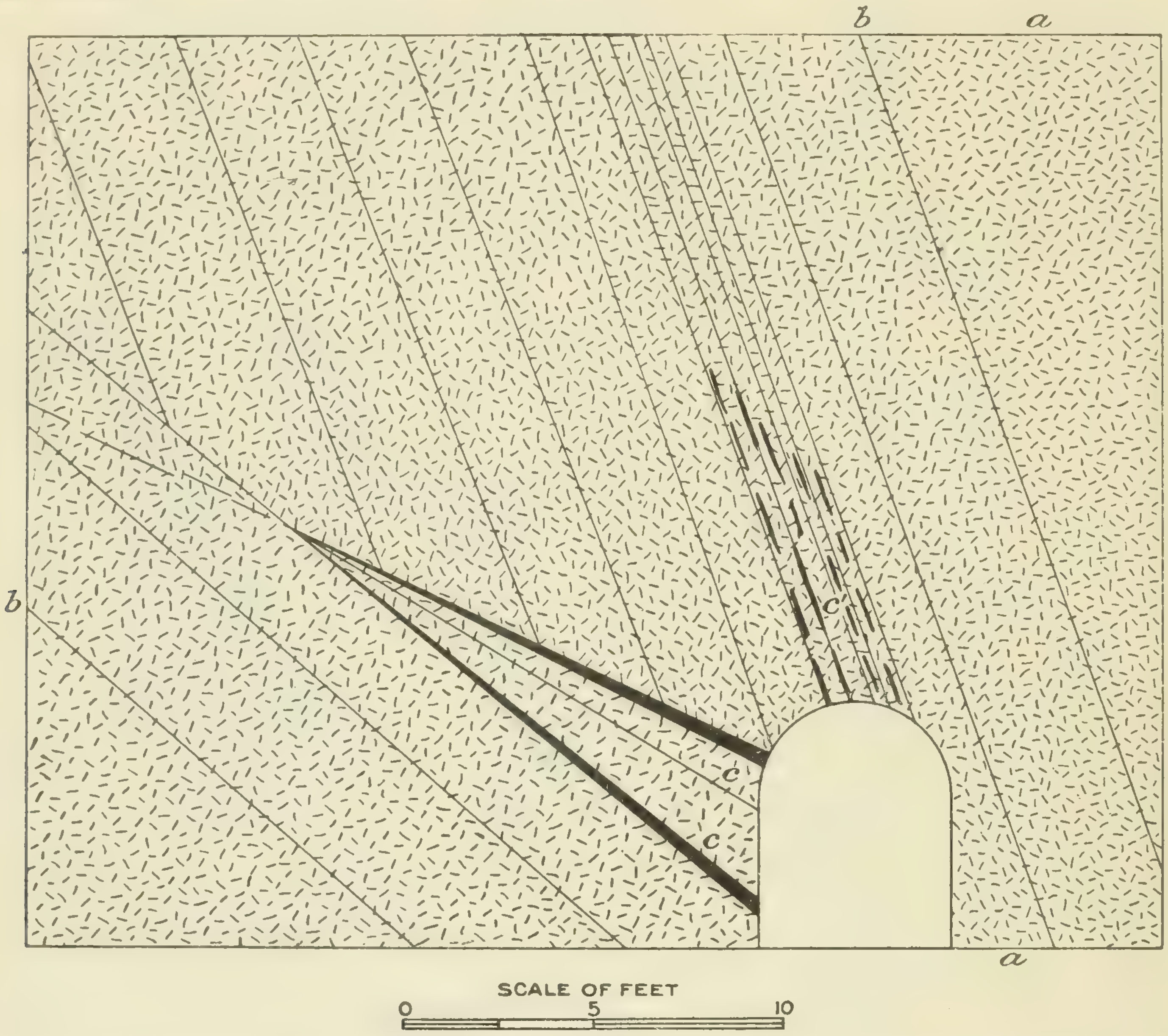

FIG. 123.—Diagrammatic sketch of cliff at mouth of tunnel on west side of Seventy-six Gulch, showing mineralization in the trough formed by two intersecting fracture zones. *a*, andesite; *b b*, etc., main fractures; *c c'*, sulphides; *c*, galena, blende, chalcopyrite, some iron pyrite, and quartz; *c'*, iron pyrite and chalcopyrite veinlets. The tunnel has been run on the junction of the two veins.

The italics are the present writer's.

The chemistry which is supposed by Professor Van Hise to account for this downward concentration is practically the same as that given by Mr. Weed.

In considering the relation of chalcopyrite to pyrite, Professor Van Hise finds that the former frequently gives place in depth to the latter. He observes:[4]

> Furthermore, the chalcocite, covellite, and bornite are very generally restricted to the upper part of the belt of ground water; deeper, the places of these minerals are

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[1] Some principles controlling the deposition of ores: Trans. Am. Inst. Min. Eng., Feb., 1900, p. 77.

[2] Geology of Wisconsin, Vol. IV, 1882, pp. 380, 393.

[3] Op. cit., p. 79.

[4] Op. cit., p. 84.

> largely occupied by chalcopyrite. Not only this, but still deeper the chalcopyrite is less prominent in many instances, and the iron sulphides more prominent. In the lower workings of many of the deeper mines the only metalliferous product found is cupriferous iron sulphides, the chalcopyrite having wholly disappeared. * * *
>
> The above order is believed to be explained by the work of downward-moving waters.

Professor Van Hise[1] also finds that the silver is likely to be richer in the upper sulphide zones, for the same reason. He observes:

> Silver is one of the compounds which holds strenuously to its sulphur. Ordinarily it is not sufficiently abundant to constitute the main mass of an ore deposit. However, since it holds so strongly to its sulphur, the silver salts are likely to be found, in the case of lead-zinc-iron compounds, most abundantly with the lead, less abundantly with the zinc, and least abundantly with the iron; and in the case of the copper-iron compounds, most abundantly with the copper and less abundantly with the iron. * * *
>
> In the case of the lead, zinc, and iron deposits, as the ores become poorer in lead and zinc they are also likely to become poorer in silver. Also, in case the copper-iron deposits become poorer in copper with depth, the silver will also ordinarily decrease in amount. Therefore the plumbiferous and zinciferous and cupriferous pyrites deep down are ordinarily lower in silver than the deposits above, which are richer in the base metals.

In the Monte Cristo district the principles enunciated by the writers before mentioned find abundant illustration. In addition to the greater precipitation of lead, zinc, copper, and silver at the higher levels, there has also been a greater precipitation of gold, as shown by the facts previously given.

CONCLUSION.

All the evidence cited points to the conclusion that the ores of the upper sulphide zone were formed by surface waters within the general period of the present climate and topography. Since these conditions are uniform with those of the present day, we should expect the deposition to be actually going on now.

EVIDENCE CONFIRMATORY OF CONCLUSION.

That the present waters are capable of dissolving the sulphides is shown in the oxidized zone, where waters oozing from the roof of the mines deposit copper as green malachite, coating the rubble in the drifts. Similarly, limonite is frequently deposited, and undoubtedly other minerals not studied.

Such solutions of the metals tending downward from the oxidized ores into the sulphide zone will naturally be precipitated on reaching the sulphides. We have independent evidence of this. The very richest ores of the district are the bunches of sulphides which are residual in the oxidized ores. In the case of the Louise mine such ores from the outcrop of a vein were said to assay in one case 15 ounces of gold, 49 ounces of silver, and 13 per cent of copper. All these values are enormously in excess of any that can be found below the outcrop within the sulphide zone proper, and since the sulphides which carry these values are the same as those in the sulphide vein below, save that they are within the zone of oxidation, the enrichment must depend upon this oxidation, and must have taken place after the formation of the present oxidized zone. This observation is similar to that recorded by Mr. Emmons in Leadville,[1] who found that the kernels of partially altered galena surrounded by the oxidation product, lead carbonate, contained more than five times as much silver as the carbonate. "In these cases," he observes, "it is evident that the action of the surface waters has been to concentrate the silver in the sulphide ore, not in the oxidized product."

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[1] Geology of Wisconsin, Vol. IV, 1882, p. 88.

If this is so we must assume, in order to explain the enrichment of the residual sulphides, that the oxidized ores of the Monte Cristo district have their gold and silver values partly leached from them. One pertinent example to show that this is probably true may be given. In the breast of the upper *O.* and *B.* tunnel there are intersecting streaks of chalcopyrite within the main vein zone, as shown in fig. 124. On the hanging wall of the vein, which has manifestly been the channel of recent water circulation, and, indeed, is so at present, the chalcopyrite is partly decomposed to a soft, black ore, which is probably largely melaconite,[2] the oxide of copper. According to information obtained, the chalcopyrite ore is of higher grade than the average ore in the district, the shipments which were made averaging, it was said, $28 or $30 to the ton without concentrating. A sample was taken from the oxidized streak, with the expectation that it would show either an increase or a decrease in values as a result of the recent water action. This sample, assayed by R. H. Officer & Co., of Salt Lake City, gave 0.06 ounce of gold and 1.65 ounces of silver, making a total value per ton of about $2.

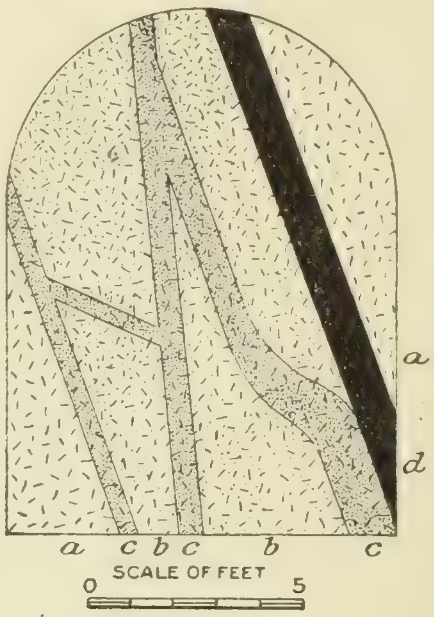

FIG. 124.—Sketch of breast of *O.* and *B.* upper tunnel in earlier andesite, showing hanging-wall streak altered and impoverished by surface waters. *a*, andesite wall rock; *b*, andesite decomposed, sparingly impregnated with sulphides; *c*, solid sulphides, largely chalcopyrite; *d*, hanging-wall alteration streak, marked by earthy black copper mineral (melaconite?) derived from decomposition of chalcopyrite, due to action of surface waters which have leached out most of the gold and silver values.

An additional evidence of the deposition of sulphides within the present zone of oxidation is contained in the instances, naturally rare, where an oxidized mineral is overlain by a younger sulphide. Such an occurrence was noted in a specimen from the Seattle vein at the head of Red Gulch, where coatings of hematite occur on joint surfaces which have been opened up by reason of proximity to the surface. This hematite has evidently formed as an oxidation product of pyrite, which is contained in the vein. It is only a thin film and is overlain by a thin crust of chalcopyrite. Of similar nature, perhaps, is the association of minerals shown in fig. 125, a sketch from a vein outcrop above the Poodle Dog trail between Monte Cristo and the pass. Here a vein of pyrite has been traversed by breaks along which oxidation has occurred, and a geode has been dissolved at the intersection of the joints. Subsequent to this a crust of quartz formed on the wall of the geode, inclosing and carrying (as in part the latest deposition) secondary pyrite. In these cases the secondary sulphide seems to have been formed on the very edge of the zone of oxidation, at periods when the fluctuation of the limit of this zone left the place of their deposition temporarily within the sulphide zone, although it had previously been within the oxidized zone. This fluctuation of the lower level of oxidation is to be explained by the fluctuation of the ground-water level, which is itself dependent upon the minor changes of climate and precipitation.

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[1] Secondary enrichment of ore deposits: Trans. Am. Inst. Min. Eng., Feb., 1900, p. 7.

[2] Possibly pulverulent chalcocite.

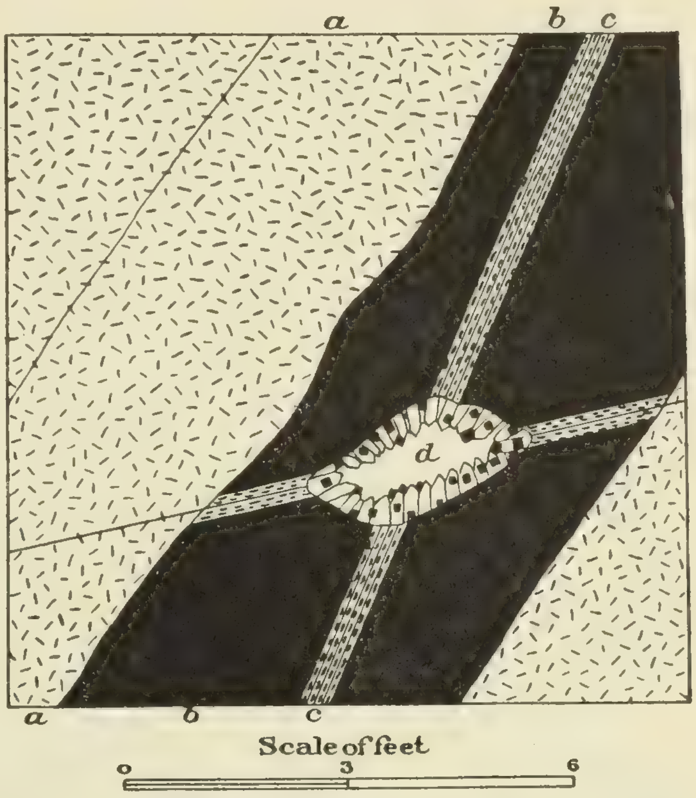

FIG. 125.—Sketch in prospect tunnel above Poodle Dog trail, showing probable precipitation of pyrite close to the boundary of the oxidized zone. *a*, earlier andesite; *b*, pyrite; *c*, earthy iron, altered from pyrite along joints; *d*, open geode, lined with quartz crystals, in and on which are pyrite crystals.

INTERMEDIATE SULPHIDE ZONE.

The relative importance of this zone is exceedingly slight. The other three zones described are universally conspicuous and definite, while this is of hardly more than theoretical interest. It is often wanting or indistinguishable.

RELATIVE AGE.

The paragenesis of minerals described shows that those of the intermediate zone are in general younger than those of the upper sulphide zone where these occur in the same specimens. They are also younger than those of the lower sulphide zone where they occur together.

DIRECTION OF SOLUTIONS.

Realgar, the representative mineral of the intermediate zone, is formed chiefly along cracks connecting directly with the surface. It is not found at great depths. Its formation, therefore, seems to be dependent upon the downward-percolating surface waters.

CONCLUSION.

The intermediate sulphide zone is then formed later than the upper sulphide zone in general, but at a lower horizon. It has been formed by waters proceeding downward from the surface. Since its relative age, as compared with the upper sulphide zone, is the same as that of the oxidized zone, these two are probably in part contemporaneous.

EVIDENCE CONFIRMING CONCLUSION.

In the Foggy tunnel, at Goat Lake, there are cases where realgar seems to have formed on broken rock since the opening of drifts, and Foreman Sloan assured the writer that he had actually observed this.

The formation of realgar in this and other cases observed seems to consist of leaching out the iron from arsenopyrite and reprecipitating the arsenic as pure sulphide, while the iron is carried away. This process seems to depend upon the greater solubility of iron sulphide as compared with arsenic sulphide.

LOWER SULPHIDE ZONE.

We have not so much information in regard to this important zone as we have in regard to the others, on account of the greater depth at which it lies, which has not been reached by any great number of explorations.

DIRECTION OF SOLUTIONS.

Evidence derived from position of ores.—On account of the small amount of deep exploration in the district, the probable persistence of ore bodies in depth can not be well stated. What has been seen leads to the impression that many of them decrease and often disappear. Cases of decrease and disappearance in depth of ore bodies which at the surface were very promising are numerous, the mineralization diminishing and practically failing entirely, while the lead or decomposed zone marking a water course continues. At the same time the evidence is not sufficient for any decided statement.

Of more value as a criterion of the direction of solutions is the position of ore bodies. This in the lower sulphide zone is in general identical with that in the upper sulphide zone, and likewise points in many cases to downward-moving solutions.

Fig. 126 is from a sketch made in the Seventy-six main tunnel, at about 325 feet in a straight line from the surface. The ores are generally arsenopyrite. The ore lens has formed, as shown, at the intersection of the main fractures *c c*, which form the lead, with the subordinate fractures *d d*. All the ore has formed on the top side of the main fracture, and none below, pointing, as in previously described cases, to solutions from above. The joints shown in the figure are all marked by ore deposition. They are undoubtedly continuous through the tonalite farther upward, and also probably downward on the other side of the main fracture, but are not easily visible on account of being close set and totally unmineralized.

Fig. 127 shows the breast of a tunnel on the west side of Seventy-six Gulch, 200 feet horizontally from the surface and considerably more vertically. The ores are chiefly pyrite and pyrrhotite, and are formed mostly on the foot wall. Moreover, the two walls of the vein converge so as to form a trough whose bottom is below the section, but as the bottom of this trough is reached the mineralization increases, indicating that this trough has held the solutions which precipitated the sulphides. Fig. 128 is a diagrammatic cross section of the breast of Tunnel No. 3, Mystery mine. This is entirely within the lower sulphide zone at a distance of about 400 feet from the surface. The ore has formed in the trough made by the intersection of two joints at a slight angle, and has not penetrated to any noticeable extent farther down.

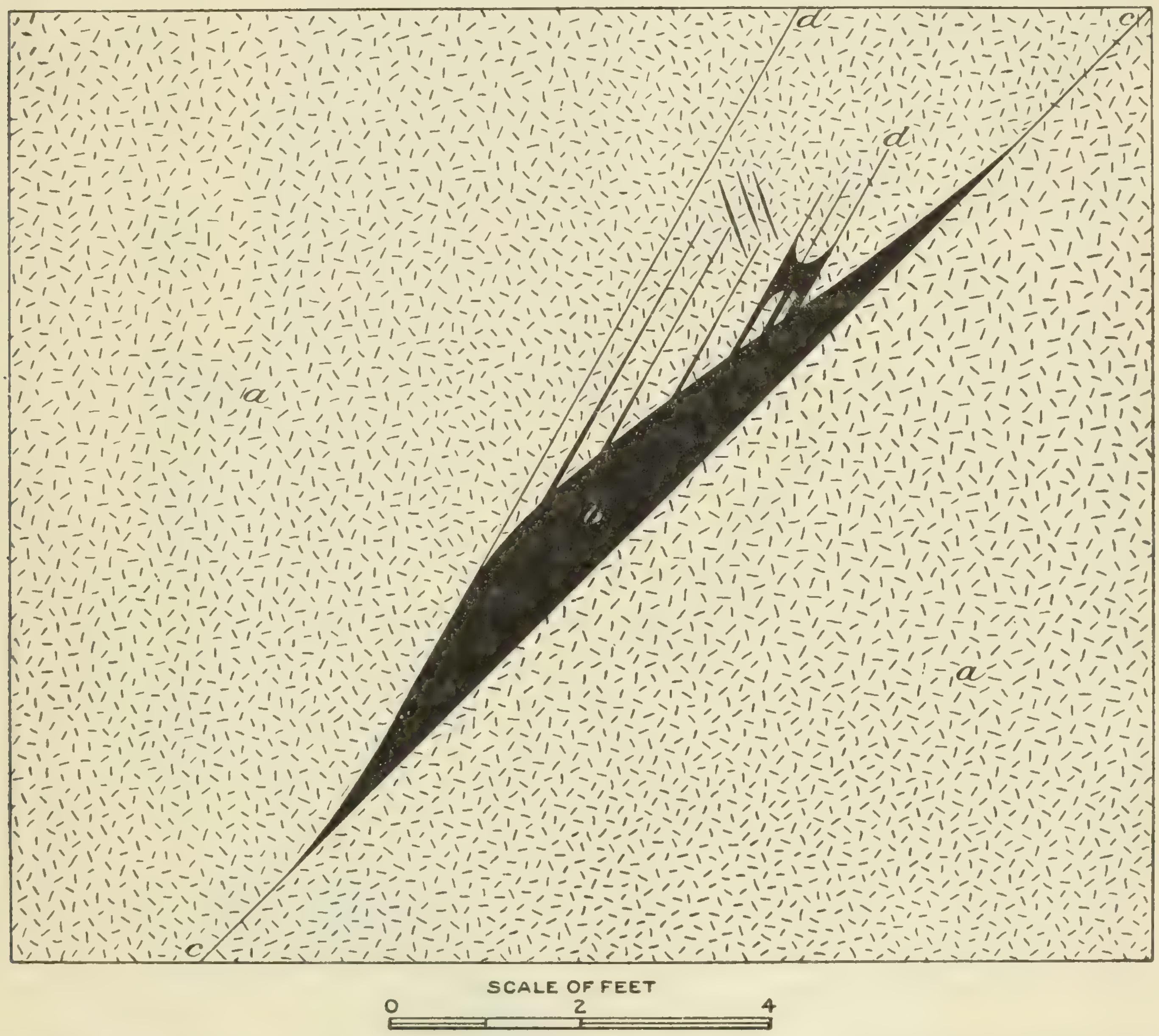

FIG. 126.—Diagrammatic sketch of ore lens in upper Seventy-six tunnel, showing precipitation at intersection of subordinate joints with the main lead, by probably descending waters. *a*, early andesite; *b*, pyrites ore, found by replacement of andesite; *c c*, prominent barren joints. This illustrates the formation of ore at the intersection of important joints and one of the stages of formation of an ore lens.

Evidence afforded by independent consideration of probable circulation during ore deposition.—The Monte Cristo district, like most of the rest of the Cascades, has no warm springs—indeed, so far as is known, no ascending springs at all. It is a region of great precipitation, so that all of the rocks from the surface downward are generally heavily charged with downward-moving waters, making their way from the rugged mountains to the deeply cut valleys. On account of the general fracturing and jointing, and on account of the otherwise generally equally impermeable character of the rocks, there are no especially favored channels of circulation, such as are formed by the alternation of permeable and impermeable strata in a folded region. Therefore, the ground water is permitted to find its way downward in the same relatively direct way that it does in soils and gravels. This, of course, is a very rough comparison, since the water circulates chiefly along the joints and very little in the spaces between, and since these joints are sometimes set at a considerable distance apart; but the general course of underground waters must be nearly the same. All the tunnels which have been driven bear out this theoretic conclusion, downward-tending waters being everywhere encountered.

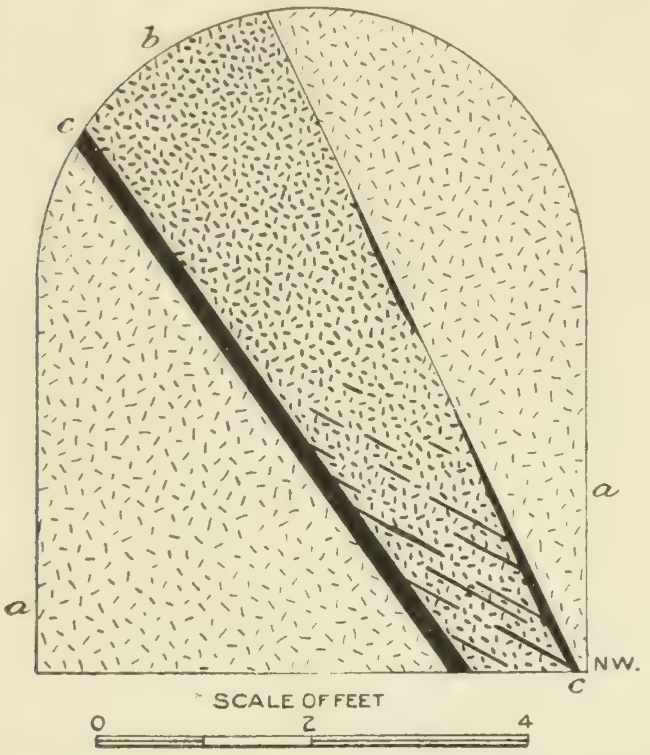

Fig. 127.—Diagrammatic sketch of breast of tunnel on west side of Seventy-six Gulch, 200 feet horizontally from surface (considerably more vertically), showing ore deposition on foot-wall streak and also in trough formed by intersecting joints. The divergence of foot and hanging walls is shown in most of the veins of the district. *a*, hard andesite; *b*, softened, decomposed andesite; *c*, sulphide ore, chiefly pyrrhotite and pyrite, a little chalcopyrite.

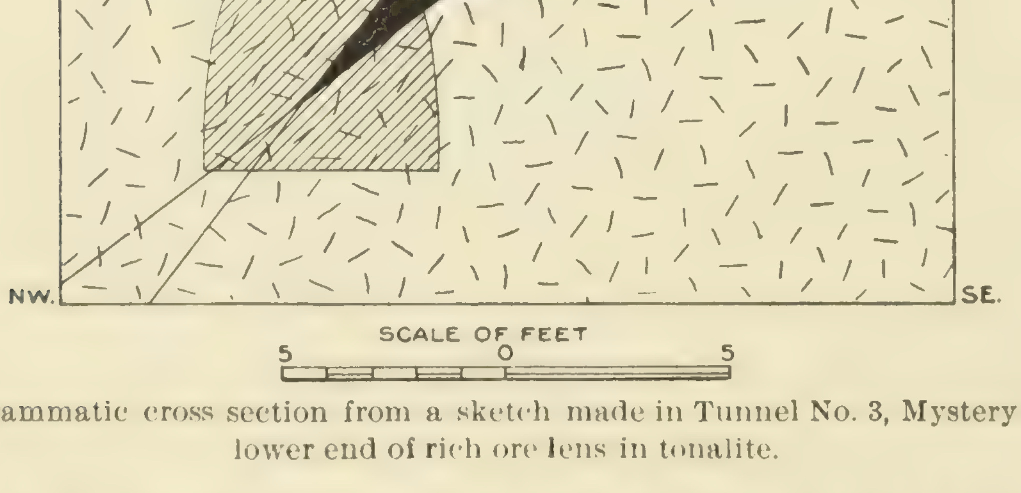

Fig. 128.—Diagrammatic cross section from a sketch made in Tunnel No. 3, Mystery mine, showing lower end of rich ore lens in tonalite.

The epoch of ore deposition has been shown to have been also one of erosion, which occurred within the Pleistocene subsequent to the upheaval of the Cascade region into a plateau. Therefore it appears that since the beginning of mineralization the general conditions of water circulation have been much the same as now. There have been no important physiographic changes, and the joints were formed before the mineralization began. The remarkably rapid cutting of the valleys shows that there was, as now, great precipitation during this period. The position of this district in the heart of the range, comprising some of the high eminences and being close to others, must from the beginning have determined the mountains as the head of water supply, where downward-moving currents were established, and it must have been in general too high to become the outlet of upward-moving solutions. The ore veins extend at the present up to the tops of some of the high mountain ridges, where the existence of an upward-moving current since the beginning of Pleistocene erosion can hardly be admitted.

GENERAL CONCLUSIONS.

It seems probable therefore that all the ore zones were formed by descending waters. It has been decided that the oxidized zone, and the intermediate sulphide zone, and part of the upper sulphide zone are actually being precipitated at present, all three being contemporaneous processes. The minerals of the lower sulphide zone are, in general, older than those of the upper, because with progressive erosion the upper zone advances on and partially displaces the lower. This is shown by the presence of large quantities of residual arsenopyrite in the upper zone. But probably much of the arsenopyrite displaced is carried down and reprecipitated. That such reprecipitation of arsenopyrite is a very recent and probably an actual process is shown by the occurrence of arsenopyrite crystals resting on calcite, which is uniformly among the latest of minerals. These arsenopyrite crystals belong to a quite different generation than the main mass of arsenopyrite, and their paragenesis shows them to be younger than the minerals of the upper sulphide zone in general. Considering this, we may believe that the lower sulphide zone may have been contemporaneous with the upper sulphide when the latter was at a slightly higher level than now, and that at present precipitation is going on simultaneously in both zones. According to this view, there has been in general a contemporaneous deposition of the minerals from downward-moving surface waters, the minerals being distributed from the surface downward, roughly in the order of their relative facility of precipitation.

INVESTIGATION OF GROUND WATER.

As the position of ground water is of importance in considering ore deposition, special attention was paid to it. The detailed observations made will not be given, but briefly speaking, the ground-water level practically coincides with the surface. In rainy weather, which occupies a large part of the time in this district, the ground-water level actually coincides with the surface. In the fair-weather intervals the ground-water level sinks, but never very far, and again reaches the surface with the next rain.

While the rocks below the surface are generally filled with as much water as they can hold, their capacity varies greatly. Those portions which are nearest the surface, and which as before explained, have open joints, have by far the greatest capacity; hence during wet weather this surface zone has abundant water circulation, while the rock underneath is comparatively dry. Within a comparatively dry tunnel in this deeper region a water course may be tapped by which a large supply may be obtained, but on the whole the amount of water in the deeper, less-jointed rocks is far less than in the surface zone.[1]

The depth of the surface zone of maximum water circulation is naturally variable and indefinite, but it may be said to be generally less than 250 feet.

RELATION OF WATER ZONES TO ORE ZONES.

It is a fact verified by abundant observation in the Monte Cristo district that the surface zone of maximum water circulation is roughly

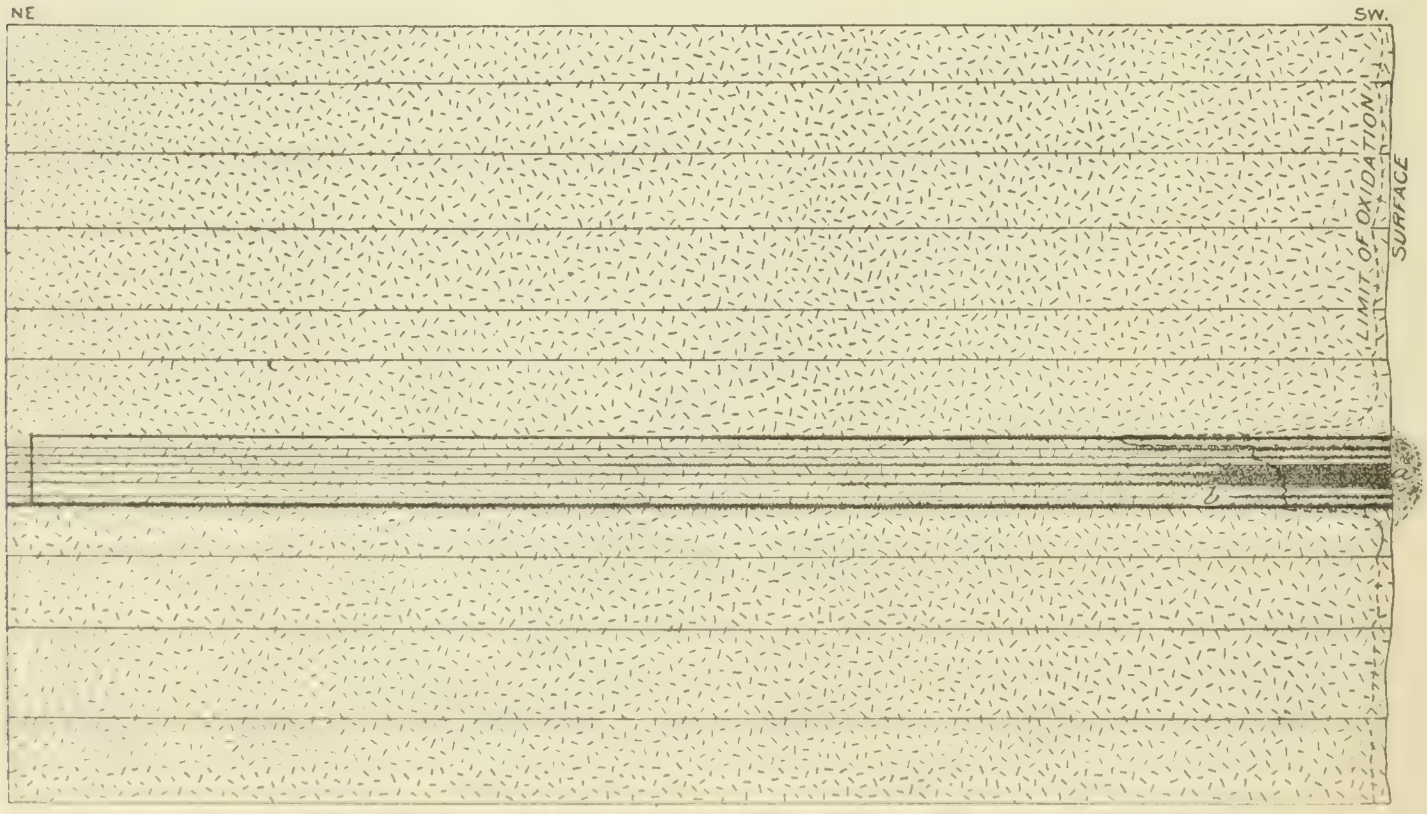

FIG. 129.—Horizontal diagram of Threadwell tunnel, in andesite, showing master joints (E.-NE.), depth of oxidation, and distribution of ore (same symbol used for oxidized and unoxidized ore). *a*, Oxidized ore; *b*, sulphide ore (pyrites with some galena). Richest ores are residual bunches of sulphides within limit of oxidation. Scale, 1 inch = 25 feet.

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[1] Mr. F. H. Newell, of the United States Geological Survey, has kindly assisted the writer in formulating these general statements from his observed facts, and has informed him that these conditions are uniform over most of the Cascades.

identical with the zone of upper sulphide deposition. The zone between the surface of the ground and the lowest level of the groundwater surface (being the zone through which this level fluctuates with changes of weather) is practically coincident with the zone of oxidation. These relations sufficiently indicate why the amount of sulphides in the upper sulphide zone is almost always much greater than that in the lower sulphide zone. Figs. 129 and 130 show two sections of the Threadwell lead on Poodle Dog Pass; one horizontal, one vertical. These illustrate a case which is frequently found elsewhere, where the ores of the lead are almost entirely found within the zone of surface circulation, which is the upper sulphide zone, the deeper portions of the rock containing only disseminated pyrites.

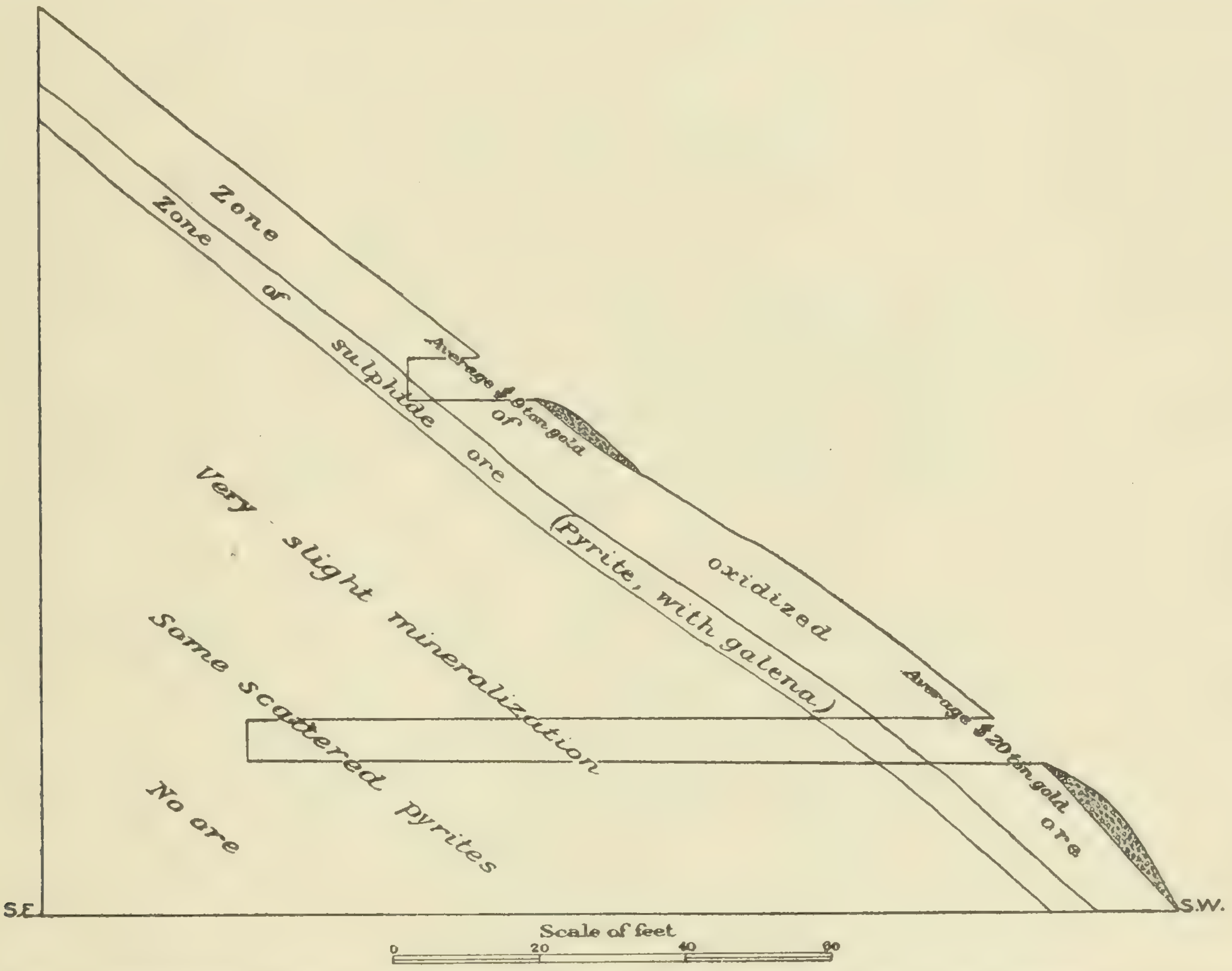

FIG. 130.—Longitudinal section on Threadwell lead, showing the relation of the different ore zones to the surface. (Lead dips 70°.)

WHERE THE ORES CAME FROM.

Relation of ores to wall rock.—It has already been explained (see p. 828) that the ores of the district seem to lie by preference in the tonalite and to a less degree in the other igneous rocks, while the arkoses are conspicuously barren. Inasmuch as the fractures and other spaces capable of being utilized by circulating waters are equally well developed in all these rocks, and inasmuch as no especial potentiality of precipitation can be found in any of these rocks as compared with others, the hypothesis suggests itself that the ores themselves may be in a general way derived from the rocks in which they by preference occur.

Mineralization along contacts.—The mineralization along the contacts of intrusive rocks (see p. 830) may also be recalled. The zone of contact metamorphism of the tonalite, which has been judged to be due to solutions proceeding from the intrusive rock, is chiefly characterized by silicification. The formation of pyrite is a frequent but subordinate feature. The altered pyritized rock in this zone showed in the one case small portions of gold and silver. The contact metamorphism in general being due to the influence of solutions from the tonalite it is probable that the pyrite and the associated small quantities of the precious metals are due to the same agency.

The mineralization described (p. 830) along the contact of the enstatite-peridotite dike is remarkable for the variety of metals found in the ores. These metals are said to include copper, mercury, cobalt, arsenic, iron, nickel, gold, and silver. Although the scant knowledge of the district forbids absolute statements, the writer has not heard of the occurrence of the metals mercury, cobalt, and nickel outside of this locality, and on this account the hypothesis suggests itself that the occurrence of these metals is directly dependent upon the enstatite-peridotite.

Mr. J. S. Diller has described enstatite-peridotite which is associated with nickel deposits in Oregon.[1] Prof. F. W. Clarke concludes that the nickel is derived from the peridotite. He says:[2]

> So far, the case appears to be clearly and conclusively settled as to the origin of the nickel silicates under discussion. Nickel is almost always present in small quantities in olivines, and T. Sterry Hunt, in reporting genthite from Michipicoten Island, calls attention to the fact that the metal is rarely absent from the serpentines, steatites, diallages, and actinolites of the Quebec group.

Prof. I. C. Russell[3] notes in the Peshastin district, which is not far southeast of Monte Cristo, ores containing copper, nickel, cobalt, and mercury in rocks consisting mainly of schist, serpentine, greenstone, etc. The serpentine is an altered peridotite, as determined by Mr. G. O. Smith. In this district both the serpentine and the derived ores contain nickel.[4] So far as we can see, therefore, there seems to be a close connection between ores containing nickel and some other of the rarer metals, and the peridotite which is so abundant in Washington and Oregon. In Oregon this connection has been shown by Professor Clarke to be a direct one, the ores being formed from the peridotite by alteration and concentration. If this is so, the same explanation probably applies to the other cases, including the occurrence at Monte Cristo. Now, the derivation of the ores near the peridotite contact from the country rock suggests the origin of the other ores of the Monte Cristo district from the country rock in which they lie—namely, from the tonalite in general; and this impression is strengthened when the slight but significant chemical differences between the ores of the peridotite contact and those in and near the tonalite are considered.

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[1] Bull. U. S. Geol. Survey, No. 60, pp. 23-25.

[2] Ibid., p. 25.

[3] Geology of the Cascade Mountains: Twentieth Ann. Rept. U. S. Geol. Survey, Part II, p. 208.

[4] The Clealum iron ores, Washington, by Smith and Willis: Trans. Am. Inst. Min. Eng., Washington meeting, February, 1900, p. 9.

Consequence of accepting the downward-circulating theory.—In a previous portion of this report it has been argued that the ores were deposited by solutions having in general a downward movement, aside from their lateral motion. If this conclusion is accepted, then it follows that the metals which these solutions precipitated were derived from the rocks in the immediate neighborhood, and by preference from the rocks inclosing the vein, although not necessarily from the immediate vicinity of the vein.

Theory.—We may, therefore, arrive at a statement of the following theory. The downward-moving underground waters had a strong lateral component of movement, so that they traversed the rocks for long distances between the points of entrance and those of emergence. During this journey they dissolved metals from the rocks, which were precipitated in concentrated form where favorable conditions were offered.

Source of metals of surface zone.—It has been shown that the minerals of the upper sulphide zone are, in general, of later formation than those of the lower sulphide zone, and that these minerals have probably been deposited by downward-moving waters since the period of approximately the present topography. The work of such downward solutions, keeping pace with erosion, would theoretically tend to concentrate certain minerals of a hypothetical preexisting vein, to the exclusion of others. This is in accordance with the views announced by Messrs. Van Hise[1] and Weed.[2] It was also the theory long held by the present writer as to the origin of the rich surface ores in the Monte Cristo district. As a test for this theory a specimen of arsenopyrite and pyrite ore from the lower sulphide zone in the Mystery mine was examined for lead,[3] this being the most characteristic metal of the upper sulphide zone. To the writer's surprise no trace of lead was found. Moreover, Mr. William E. Sutton, the superintendent of the Monte Cristo mines, has informed the writer in a letter that in the deeper workings the arsenopyrite, pyrite, and pyrrhotite ores are almost always free from lead. This evidence taken altogether is still slight, but so far as it goes it makes against the theory of concentration of the lead from preexisting ores, similar to those of the present lower sulphide zone. If this theory is discarded there remains only the hypothesis that the ores have been concentrated from a minutely disseminated condition in the surrounding rocks.

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[1] Some principles controlling the deposition of ores: Trans. Am. Inst. Min. Eng., February, 1900.

[2] The enrichment of gold and silver veins: Trans. Am. Inst. Min. Eng., February, 1900.

[3] By Mr. G. F. Steiger, of the U. S. Geological Survey.

Source of metals in general.—The most abundant mineral in the ore deposits is iron. This is also extremely plentiful in the igneous rocks, especially the tonalite. It is contained in the pyroxene, hornblende, and biotite of this rock, but chiefly in the abundant magnetite. So plentiful is the iron that the leaching of this metal from a relatively small volume of tonalite would afford, on precipitation in concentrated form as pyrite, a sufficient volume for all the ore deposits. The concentration of the iron from a few feet of tonalite and its precipitation as pyrite along a fracture would make a considerable veinlet of this mineral.

The other metals of the ore deposits are arsenic, lead, copper, zinc, antimony, silver, and gold, abundant in approximately the order named. The dark-colored silicates of igneous rocks are known to contain small quantities of these metals, and the magnetite of the tonalite may also perhaps contain them. A specimen of fresh tonalite was tested by Mr. G. F. Steiger for arsenic, by the Marsh test, with no results. Although this is not favorable to the theory advanced, yet analyses of larger quantities of the rock, and especially of the mechanically concentrated ferriferous minerals, might yield different results.

Source of the gangue.—The nature of the gangue is more significant of the source of the veins in this district than is the nature of the sulphides. The ores of many districts contain large quantities of gangue minerals of a composition entirely unlike that of the inclosing rock, showing, first, a high degree of circulation and concentration by the agents of ore deposition, and, second, the remote origin of the gangue, and, inferentially, of the metallic minerals. For example, the great quantities of barite as gangue mineral in the ore deposits of Aspen, Colo., which lie in limestone and dolomite, afford immediate evidence of the derivation of the vein material from some point outside of the inclosing rock, and of the formation of the vein by vigorous circulations. The occurrence of fluorite in many ores is another case in point. In the Monte Cristo district there are only two gangue minerals, properly speaking—calcite and quartz. As already explained, calcite is among the last formed minerals and is not associated as a contemporaneous gangue with the ore deposits in general. Quartz, however, is contemporaneous with all the ores. Now silica is abundant in most rocks and may easily be taken into solution by surface waters, as has been abundantly proved. The calcite is almost certainly derived from the decomposition of the soda-lime feldspars of the tonalite and andesite, as appears from the study of thin sections of these rocks, where the process is found going on.

Two other minerals have in some cases claims to be considered gangues. These are blue amphibole and epidote. Both of these have been found to be alteration products of the country rock in or close by the veins, the blue amphibole being produced in the tonalite chiefly at the expense of the original ferromagnesian minerals, and the epidote in the andesite as a product of the decomposition of the basic feldspars.

Therefore all the gangue minerals of the ores are such as may be accounted for by derivation from the country rocks.

Alteration of wall rock.—The slight alteration of the country rock in the vicinity of the veins and ore deposits is one of the striking features of the Monte Cristo district. Both the tonalite and the andesite, where these form the country rock, are generally hard and apparently not much altered only a few inches from the ore. The portions of the country rock included within the vein itself are often decomposed, but quite as often they remain hard.

Microscopic examination of the foot wall of the main vein in the Mystery mine shows an altered yet easily recognizable tonalite, distinguished by being traversed by numerous parallel cracks and seams, without crushing. The feldspars are partly altered to fine muscovitic aggregates, while of the original dark minerals only the pale-green hornblende persists, the others having been replaced by a fine mat of actinolite fibers. The magnetite has been almost entirely extracted. In other specimens of the tonalite wall rock there is an abundant development of blue amphibole. In this case the biotite has often not been attacked to so great an extent as have the other original ferromagnesian minerals, which have disappeared and are represented by a nearly isotropic greenish brown mass of decomposition products. The secondary blue amphibole is in irregular plates and also more or less perfect crystals. In this case also the magnetite has been extracted from the rock.

The andesite near veins is generally silicified, like the same rock within the veins. Silicification may go on so far as to perfectly replace the original rock by quartz, forming a true jasperoid. Another common alteration is to epidote. These two forms of alteration, like the two forms described in tonalite, denote distinct chemical processes in diferent parts of the wall rock.

SUMMARY.

The rock series of the Monte Cristo district has at its base a hypothetical granite, not actually determined, although recognized in other neighboring districts. The lowest actually determined formation seems to be a series of heavy arkoses. These are capped by thick andesitic flows and tuffs, and these by thick basalts, with a sparing amount of rhyolite, which is probably intermediate in age between the andesites and the basalts in general. The basalts are overlain by later andesites, which constitute the youngest of the rocks. Probably between periods of the early andesites and the basalts came intrusions of tonalite, which by contact metamorphism transformed narrow zones of the intruded rock into silicified phases and schists.

These rock formations are all Tertiary, ranging from Eocene to late Pliocene or early Pleistocene. In late Tertiary times the rocks (with the exception of the later andesite, which was not yet poured out) were folded and subsequently planed down by erosion. Then in late Pliocene or early Pleistocene time came an uplift of the planed surface to form a plateau. This uplift was accompanied by the extrusion of the later andesite and by fracturing. Immediately after the inception of the uplift the dissection of the present topography began, and with it the deposition of the ores.

These ores have formed chiefly along the joints and fractures, and are often especially localized at the intersection of different fractures. The areas of most profound fracturing are in general the areas of greatest mineralization. The ores are especially abundant in the tonalite; to a less extent in the andesite.

In the observed veins of the district it is found that the ores are most abundant near the surface. There is a rough succession, from the surface downward, of galena, blende, chalcopyrite, pyrite, and arsenopyrite. The upper zones, characterized by galena, blende, and chalcopyrite, contain more gold and silver than the lower zones, characterized by pyrite and arsenopyrite.

Upon various grounds it has been concluded that the upper sulphide zone, which contains the most and the richest ore, was deposited, largely at least, since the development of approximately the present topography, by downward-tending waters. Lead, one of the most conspicuous metals of this zone, is not known to be present in the lowest ores, and so is not regarded as having been derived by the concentration of ores like those in the lowest zones; but is, perhaps, as the known facts indicate, an original deposit by descending waters. This theory involves the derivation of the lead ores from the surrounding rock. The lower sulphide zones afford less evidence as to their origin, but what there is tends in the same direction as that for the upper zones, so that the general suggestion is deduced that all the zones were precipitated, in part simultaneously, by downward percolating waters, the different belts of minerals being precipitated in order according to their relative solubility. Similar phenomena in other regions, and the known chemistry of such phenomena, support these deductions derived from independent local evidence.

PRACTICAL CONCLUSIONS.

In the Monte Cristo district the best veins should be looked for in or within a moderate distance of the tonalite, and should be especially looked for along the predominant steeply dipping east-northeast striking system of joints. Within the veins the best ores, as regards both quantity and quality, will probably be found near the surface, so that calculations for mining the deeper ores can not be made on the basis of the surface ores. Both the mineralogic character and the gold and silver content of the ores can, in general, be counted upon as changing in depth, and plans for ore treatment must take this into consideration. These changes in depth will be most regular and certain in regions where there are no very intense fracture zones. Where there are such they may bring about the irregular downward extension of surface conditions to considerable depths.

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